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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

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MEETING

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

SUBCOMMITTEE ON THERMAL-HYDRAULIC PHENOMENA

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TUESDAY,

NOVEMBER 12, 2002

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ROCKVILLE, MARYLAND

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The Subcommittees meet the Nuclear
Regulatory Commission, Two White Flint, North Room
T2B3, 11545 Rockville Pike, Maryland, at 9:30 a.m.,
Dr. Graham Wallis, Chairman, presiding.

COMMITTEE MEMBERS:

GRAHAM B. WALLIS, Chairman

SANJOY BANERJEE, Consultant

THOMAS S. KRESS, Member

FREDERICK MOODY, Consultant

VICTOR H. RANSOM, Member

VIRGIL E. SCHROCK, Member

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ACRS STAFF PRESENT:

PAUL BOEHNERT, Staff Engineer

ALSO PRESENT:

STEPHEN M. BAJOREK, NRC

LARRY HOCHREITER, Penn State University

RALPH ROSAL, Penn State, University

A-G-E-N-D-A

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8:30 a.m.

CHAIRMAN WALLIS: The meeting will now come to order. This is a meeting of the ACRS subcommittee on thermal-hydraulic phenomena. I'm Graham Wallis, Chairman of the subcommittee.

The other ACRS members in attendance are Tom Kress and Victor Ransom. ACRS consultants in attendance are Sanjoy Banerjee, Fred Moody, and Virgil Schrock.

In today's meeting the subcommittee will discuss the status of the NRC Office of Nuclear Regulatory Research's rod bundle heat transfer program, underway at Pennsylvania State University.

Tomorrow, and the next day, we will continue review of the Framatome ANP-Richland S-RELAP5 realistic code version, and its application to PWR large-break LOCA analysis.

Portions of this meeting will be closed to the public for discussion of information considered proprietary in Framatome ANP-Richland, Incorporated.

Mr. Paul Boehnert is the cognizant ACRS staff engineer for this meeting.

The rules for participation in today's meeting have been announced as part of the notice of

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1 this meeting, previously published in the Federal
2 Register, on October 23rd, 2002.

3 A transcript of this meeting is being
4 kept, and the transcript will be made available, as
5 stated in the Federal Register Notice. It is
6 requested that speakers first identify themselves, and
7 speak with sufficient clarity and volume, so that they
8 can be readily heard.

9 We have received no written comments, no
10 request for time to make oral statements from members
11 of the public.

12 We will now proceed with the meeting, and
13 I will call upon Dr. Steven Bajorek, from the NRC's
14 Office of Nuclear Regulatory Research to begin.

15 DR. BAJOREK: Thank you very much. This
16 is Steve Bajorek from the Office of Research. What we
17 would like to do this afternoon is to continue on a
18 series of meetings with this subcommittee that
19 explains and gives the status of eight of our
20 experimental programs.

21 In the past we've had the tests that are
22 being run for phase separation at Oregon State. We've
23 looked at the work by V. J. Dhir at UCLA for subcooled
24 boiling model development.

25 Today we would like to give you a status

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1 and review of the RBHT program being conducted at Penn
2 State University.

3 First, before I go any further, Jack
4 Rosenthal wanted me to say that he apologizes for not
5 being able to make the meeting today. He had a
6 doctor's appointment that I guess the doctors would
7 not let him out of. But he wanted me to let you know
8 that he would truly rather have been here.

9 The RBHT program was started, I believe,
10 in about 1998. Gene may correct me if it was earlier.
11 The first two to three years of the program have been
12 tied up, primarily, with construction, calibration of
13 the bundle.

14 And at this time we are very pleased to be
15 able to report that we've continued, or we've
16 completed the bundle, or Penn State has, and they've
17 run a series of reflood experiments, and now after a
18 couple or three years, we are finally getting to the
19 point where we have usable data.

20 And a group of us from the NRC has been up
21 to Penn State, a couple of times, to inspect the
22 facility, to witness some of the tests. And our
23 initial reaction is we were very much impressed with
24 what they've been able to do, the quality of the data
25 we believe is quite high.

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1 And it is hitting the objectives that were
2 envisioned for this test program. If you take a look
3 at the existing experimental data for reflood, be it
4 from FLECHT SEASET, ACHILLES, there have been some
5 shortcomings, either in that there weren't sufficient
6 amount of instrumentation, or there weren't
7 measurements that covered all of the various
8 parameters that are believed to be important in the
9 development of a truly mechanistic model for reflood
10 heat transfer.

11 CHAIRMAN WALLIS: Could I ask you now, is
12 the objective of this work is only to get data, or is
13 it to develop models?

14 DR. BAJOREK: It is both. It is first to
15 develop the data, and then to develop the models.

16 CHAIRMAN WALLIS: Because I think it would
17 be very useful to predictions, as you do the
18 experiments, so that you learn, you don't get a
19 mountain of data, and then try to figure out what it
20 means.

21 And then as you find you are learning
22 things, you change the models, and then you maybe fine
23 tune the data, or something. But it is dangerous just
24 to take a lot of data without theory.

25 I don't see, yet, any predictions.

1 DR. BAJOREK: The Staff has not made any
2 predictions of this. However, as part of
3 understanding the facility, Penn State has used
4 COBRA/TF to make predictions of the data, before they
5 run the tests, and they've also followed up with their
6 own model development, to try to predict the data that
7 they were able to obtain.

8 This is -- one, it is very important,
9 because you want to make sure that when you run the
10 tests you don't impose conditions that are going to
11 melt the rods, or do something that you don't want to
12 happen to the facility.

13 DR. RANSOM: Wouldn't it be better to use
14 TRAC-M for that purpose?

15 DR. BAJOREK: Yes, it would.

16 DR. RANSOM: And in fact, what I found in
17 the past, almost invariably with the experiments that
18 are made like this, that they create their own models,
19 they aren't integrated with the main objective, which
20 is to get it into the main systems code.

21 And so this creates a disparity later on,
22 that the modelers, more or less, are accused of tuning
23 the codes to try to get agreement when, in reality,
24 the heat transfer correlation, or coefficient, has
25 been derived from some model, you know, which the

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1 experimenter used.

2 So it would be nice if these two
3 dovetailed.

4 DR. BAJOREK: No, I agree. I think that
5 it would have been a lot better if we had TRAC-M ready
6 to go, and were able to use it to make it the
7 predictions.

8 Now, using COBRA/TF, however, we don't
9 think is tremendously far off at this point. In TRAC-
10 M right now is a reflood model that was developed in
11 the late '80s, early '90.

12 And Joe Kelly, who has looked at this in
13 a lot more detail than any of us, has concluded that
14 this model just needs to be ripped out of the code,
15 and we need to go back to something else.

16 The first cut of this is going to be what
17 are calling and interim reflood model. And it is
18 going to look a lot like COBRA/TF. We are going to
19 try to take it back to that, and then start to replace
20 those models with improved ones that we can get from
21 the RBHT.

22 DR. RANSOM: One of the disadvantages of
23 that approach is sort of like, you know, the subcooled
24 V. J. Dhir's work, you create a model that doesn't fit
25 in the structure of what you are trying to put it in.

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1 So somebody in the end is going to have to
2 make compromises, you know, to dovetail these
3 together. And I would guess the same thing is true
4 with TRAC-M, and -- I don't mean TRAC-M, but the
5 COBRA/TF, that that is probably driven a lot by the
6 familiarity of the principal investigator with that
7 code.

8 But that doesn't help get it into, say,
9 TRAC-M, or get new models into TRAC-M.

10 MR. SCHROCK: I think it would be helpful
11 if there was available a brief assessment of what it
12 is about the past work that has been found inadequate,
13 and how those inadequacies motivate and define new
14 experimental requirements.

15 I don't think we have ever heard that,
16 clearly, about this program.

17 DR. BAJOREK: Actually I would have to go
18 back and look, but I believe that when this program
19 was started in '97, '98, that foundation was laid out.
20 But I would have to go back and check that.

21 Now, one thing that --

22 MR. SCHROCK: Well, I don't think that is
23 getting at the intent of my comment. I think we are
24 about to go through discussion of details of
25 instrumentation on a new set of experiences that

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1 would, essentially, retilling ground that was very
2 heavily cultivated over a period of 15 years, in the
3 past.

4 And I think we need to be reminding
5 ourselves, as we go through this, what are the clear
6 objectives that we need to keep focused on, and not
7 just begin again and say, well, rod bundle transfer is
8 important in large-break LOCA analysis, and we have to
9 do it right, and we don't think we did it well enough
10 before.

11 I don't know why we don't think we did it
12 well enough before. I'm not arguing that it was done
13 well enough before. But what I'm looking for is clear
14 explanations of how we know now that it wasn't done
15 adequately before, and what we think we can do to make
16 it adequate in a new set of experiences.

17 I think you have to keep that sort of as
18 a point of focus in these discussions.

19 DR. BAJOREK: Well, would it help, maybe
20 this -- I think one of the problems that I think we've
21 encountered, as we start to talk about what is in the
22 code, and what we get from the test programs, is it
23 starts to get too much for one meeting.

24 Would it be a decent idea to take meeting,
25 in the future, describe what is in TRAC-M at this

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1 point, and how we are going to take these data and
2 change the models in what order?

3 MR. BOEHNERT: Well, we have a meeting
4 scheduled in December to discuss TRAC-M, maybe you
5 want to work that into the agenda.

6 DR. BAJOREK: We can work some of that in
7 there.

8 MR. BOEHNERT: Yes.

9 CHAIRMAN WALLIS: Joe Kelly gave us a
10 presentation, I would say, a couple of years ago,
11 where he pointed out some of the anomalies in the
12 present code, which needed to be fixed. I remember
13 that.

14 But it wasn't quite clear to me how this
15 tied in with this program, and what was going to be
16 measured this time, which wasn't measured last time,
17 with flood tests, which would resolve his
18 difficulties.

19 So I think it would be useful if we could
20 do that next month. Is Joe, who is the guy who is
21 coordinating this with the model development?

22 DR. BAJOREK: Well, Joe is the guy who is
23 in charge of the code development, and I work with
24 Joe, looking at the models that are going into the
25 code, but also taking a look at the experimental

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1 programs.

2 CHAIRMAN WALLIS: So you are the bridge
3 between the theory and the experience?

4 DR. BAJOREK: Yes.

5 CHAIRMAN WALLIS: So maybe you are the guy
6 who needs to come back in December.

7 DR. BAJOREK: Well, I will be here,
8 anyway.

9 CHAIRMAN WALLIS: I will ask again why it
10 is you again.

11 (Laughter.)

12 DR. BAJOREK: Maybe we will get more of
13 our management there, or get an answer for it. But,
14 no, granted that we do need to lay that out, and we
15 have not done a real good job, at this point, at
16 showing how we are going to take these data, and
17 integrate these into the code.

18 But let us take that as an action, and
19 start working that in at the next meeting.

20 DR. SANJOY: One other thing, just to
21 continue Virgil's point. With the subcooled boiling
22 work you made a clear case to us about what data was
23 missing, and why that program had to go forward.

24 What I guess is still not clear to me, at
25 least, I don't know to others, is what is the case for

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1 these experiments at all? I mean, at some point this
2 case was made way back in history, the anecdotal
3 evidence, that people at CSAU thought the tests were
4 needed, therefore we did it, or whatever.

5 But I think we still need to make that
6 case, once again, and continue to make that case.
7 What is missing, why are we doing it, what are we
8 going to find, how is it going to improve the models.

9 And that doesn't come through, from
10 reading the material.

11 DR. BAJOREK: Okay.

12 CHAIRMAN WALLIS: Then we should ask, are
13 we finding it, as we begin to look at the results.

14 DR. RANSOM: Right.

15 DR. BAJOREK: Part of the answer as to, I
16 think, what has been missing, the earlier data, you
17 see a little bit of it. This wasn't the intent of the
18 overhead here.

19 But we have, overall, four major series of
20 tests which are planned. Larry is going to talk with
21 you, later this afternoon, describe the bundle, and
22 talk about the transient forced reflood tests that
23 were run since about last May.

24 Penn State has managed to run on the order
25 of 32 experiments under varying conditions to cover a

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1 range of reflood rates, pressures, and subcooling.
2 This kind of gives us our base cases for the reflood
3 model.

4 The next couple of series of tests are
5 going to start to go into questions on the reflood
6 model that we don't believe have been adequately
7 answered in previous test series.

8 Jumping here to the third one, the steam
9 cooling, the droplet injection tests. One of the
10 question marks that we've run into is what is the
11 convective enhancement that occurs when you have
12 droplets within the steam flow.

13 Earlier tests have been run, I believe, in
14 a two by two bundle at UCLA, using glass beads, show
15 that you get much better heat transfer when you have
16 this dispersed phase in there.

17 But we really haven't been able to sort
18 that out of earlier tests like FLECHT or FLECHT
19 SEASET, to try to get at that individual mechanism,
20 Penn State is going to be running a series of tests,
21 one with steam only, but also with a rake of droplet
22 injectors in the bottom of the facility.

23 So we are going to be able to get
24 experimental data that gives us a known droplet
25 content for a given steam flow. So we will be able to

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1 get that individual mechanism.

2 Larry is going to describe the
3 instrumentation for this bundle, and that goes in
4 here, here, the first, third and fourth. Some
5 questions on what are the details that go on at the
6 quench front, what is the progression of the void
7 fraction in that vicinity, as it changes with
8 subcooling and reflood rate.

9 Well, from earlier tests like FLECHT, the
10 DP cells were, I think, a foot apart. Other
11 facilities like G2, which is commonly used, I think
12 they were two feet apart. It doesn't give us anywhere
13 near the detail to try to determine what was the flow
14 like right where quench was occurring.

15 The other thing that was very difficult to
16 get out of earlier experiments, was some of the
17 droplet information. When we were trying to use the
18 FLECHT SEASET data in development for the models for
19 best estimate at Westinghouse, trying to determine
20 what was the reflood droplet size, what was that
21 initial size, and how did it chaNge as it went through
22 grid spacers.

23 It was very difficult, because in the
24 FLECHT SEASET experiences you had measurements of, I
25 think, 3, 6 and 9 feet, but very few droplets. The 3

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1 foot may have half a dozen droplets, the 9 foot, for
2 a couple of tests, may have only on the order of 50 to
3 100.

4 And they weren't broken down for all of
5 the tests, there were only some very select ones.
6 Now, a lot of that had to do with the instrumentation
7 at the time, which really meant taking some good high
8 speed movies, and get somebody with a good set of
9 eyes, projecting it on a screen, and going frame by
10 frame, to look at how the droplet changed.

11 It took forever and a day to try to get
12 information for one test. With newer instrumentation
13 we are able to get that much quicker, you can get it
14 at multiple locations, and we are going to be able to
15 get better models for how does the droplet originate,
16 how does it change as it goes through an individual
17 grid, and how quickly does it evaporate away in a
18 steam of a certain temperature.

19 All of that information was there, to an
20 extent, in some of these earlier experiments, but it
21 was so sparse it made it very difficult to get models
22 that you were confident in, and get them quantified,
23 to a degree of accuracy that you could apply them,
24 then, to a PWR, or a BWR experiment.

25 So I think where you will see some of

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1 those questions answered is what you are going to get
2 that is going to improve the models, and where those
3 uncertainties are. It is in those processes that are
4 right now buried in the reflood models, that we can't
5 get at, unless we get some of the better experimental
6 information.

7 So we've got four series to try to
8 segregate that out, using the newer instrumentation.
9 The second one, which I haven't really mentioned on
10 here, those add almost a more basic question, as how
11 do the flow patterns develop and transition within a
12 rod bundle.

13 CHAIRMAN WALLIS: How do they measure
14 interfacial drag?

15 DR. BAJOREK: We don't measure it
16 directly. I guess I think of it more in terms of
17 using the increased number of DP cells to get at the
18 change in void fraction, as opposed to a direct
19 measurement, then using carryover measurements of the
20 steam flow, and liquid flow, coming out of there to
21 deduce what should be the right interfacial drag.

22 DR. KRESS: Is that between the steam and
23 the broad bundles?

24 DR. BAJOREK: Steam and the droplets or
25 the films, which were there.

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1 DR. SANJOY: What was done at WINFRED?

2 DR. BAJOREK: Those were the ACHILLES
3 tests. I'm trying to remember, or recall exactly what
4 was there in those tests. I don't believe they had
5 much in the way of steam probe measurements in those
6 tests.

7 I think it was more of a traditional rod
8 bundle. I want to say it was on the order of 50 or 60
9 rods. The rods were instrumented, there was
10 relatively sparse steam probe measurement, no droplet.
11 Larry, do you remember what that is?

12 DR. HOCHREITER: Larry Hochreiter, Penn
13 State. The WINFRED tests were, basically, a set of
14 reflood experiments. It had, I think, a 69 rod
15 bundle. They did have delta P cells on it, but I
16 don't remember them ever reducing that to get any void
17 fraction data.

18 And they primarily looked at temperatures,
19 and the heat transfer, itself. To my knowledge there
20 was no droplet data, there were no steam probes in
21 that facility, that I'm aware of.

22 So it is really their first shot at
23 running a reflood test. And I think what it was used
24 for was basically to confirm the types of heat
25 transfer that they would have been predicting for a

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1 Sizewell type plant.

2 I think it was really designed to give
3 them a basis for looking at other tests, and other
4 models.

5 DR. SANJOY: Why didn't they use the DP
6 cells to get the void fraction?

7 DR. HOCHREITER: I don't know.

8 DR. BAJOREK: Larry, I think they did get
9 void fractions out of the DP cells, just for a few of
10 the tests.

11 DR. HOCHREITER: Okay, I just never saw
12 it.

13 DR. SANJOY: Are the databases available
14 to us?

15 DR. BAJOREK: Yes, we have some of them,
16 it is hard to find. We do have a report, and some of
17 the experimental data. But, again, I forget some of
18 the details of the bundle, but it wasn't a complete
19 set of data.

20 You get the heat transfer coefficients and
21 the void fractions, but you don't have droplet sizes,
22 you don't have carryover fractions, and if you don't
23 have the steam temperature measurements, you really
24 don't have that consistent set of information.

25 DR. SANJOY: Do you remember the pressure

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1 range?

2 DR. HOCHREITER: I think it went up to 60
3 PSI four powers.

4 DR. BAJOREK: Yes, it is low pressure,
5 there is a lot of low pressure data with it.

6 DR. HOCHREITER: They also use it for
7 level swell, they also use it to look at the effect of
8 nitrogen injection. In fact that became the
9 International Standard Problem number 25, I think.

10 DR. KRESS: The effect of the droplets, as
11 best as I remember, was pretty sensitive to the size
12 distribution for a given amount of liquid in there.

13 Will we be able to get size distributions
14 out of the --

15 DR. BAJOREK: Yes, yes.

16 DR. KRESS: Even inside of a bundle?

17 DR. BAJOREK: Yes.

18 DR. HOCHREITER: Well, I will explain
19 that.

20 DR. KRESS: Line of sight.

21 DR. HOCHREITER: That is right.

22 DR. BAJOREK: But line of sight, but you
23 get droplet sizes, and also total carryover fractions,
24 which I think are really very important to have in
25 these tests.

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1 I was going to save this more for the end,
2 but since a couple of the questions have kind of come
3 up along this, where does it really fit in with our
4 plans for the model development.

5 As I mentioned, some of the reflood tests
6 are complete at this point, and over the next couple
7 of years they will be moving into the interface, what
8 we re calling the interfacial drag tests, and these
9 droplet injection tests, over the next couple of
10 years.

11 Right now our plate is fairly full when it
12 comes to our ability to take all of the data that we
13 have from our experimental programs. Because of the
14 need for advance plans, our work right now is trying
15 to take the ATLATS data, and develop models for phase
16 separation that we would use in TRAC-M.

17 We did take your suggestion to heart back
18 in June or July, about trying to integrate some of the
19 subcooled boiling models in earlier. Originally we
20 weren't going to be able to get to that, but due to
21 some clever accounting we were able to start that work
22 a little bit earlier.

23 And we have a student at UCLA who is
24 taking their models, put them into a stand-alone
25 package, which I've asked at this point, so that we

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1 can integrate this into the code.

2 The mechanistic model development --

3 MR. SCHROCK: What happened to the interim
4 reflood model?

5 DR. BAJOREK: That is ongoing right now.
6 That is -- the interim reflood model is where we are
7 taking out the existing package in TRAC-M, and
8 essentially replacing it with the package that had
9 been there, or very close to the one in TRAC-PF1,
10 which is about as close to COBRA/TF as you can get,
11 the way the numerics are right now in TRAC-M.

12 MR. SCHROCK: See, the trouble I have,
13 Steve, is that I'm convinced that when you do detailed
14 experimentation that is related to mechanistic model
15 development, that you have to have some idea of what
16 you mean by mechanistic reflood models, in order to
17 establish what is required of the experiences, what is
18 to be measured, where, how accurately, and so forth.

19 I don't see how you know what those things
20 are from the description that you've given here. So
21 do you learn that from old models that you've had in
22 the code, codes, that you've twitched, and done
23 different things with, to gain some insight?

24 Or what do you do to get all of that down?

25 And how can you convey that to us?

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1 DR. BAJOREK: I think the right way to do
2 that is to step through some of the existing models in
3 the code, show where we think there are shortcomings.
4 And, more importantly, point where we think they can
5 be improved, within the numerics of the code.

6 In answer to your question, have you done
7 that, I haven't done that with TRAC-M. But in working
8 with code like COBRA/TF, you can find that changing
9 models for interfacial heat transfer interplay with
10 steam temperature, which plays upon the droplets size,
11 which then impacts your heat transfer at the top of
12 the rod.

13 MR. SCHROCK: But what does models mean,
14 here, in this context; is that correlations, or is it
15 first principle analysis of the process, or what?

16 DR. BAJOREK: I would say it is,
17 primarily, correlations. It is those models and
18 correlations for the various processes involved in
19 reflood heat transfer. Interfacial heat transfer, the
20 droplet breakout, heat transfer coefficients from the
21 rod, as a function of the regime, and also the droplet
22 content, transition boiling near the quench front.

23 And I think entrainment, that is another
24 one that is very difficult to pin down.

25 MR. SCHROCK: So it is models meaning

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1 correlations in a format compatible with the structure
2 of TRAC and RELAP type codes?

3 DR. BAJOREK: Almost. Because one reason
4 this has deliberately been delayed is in order to
5 install a third field into TRAC-M. Right now we are
6 dealing with the code numerics that does not allow us
7 to model, simultaneously, droplets and liquid films.

8 And we want to start that work early next
9 year, so that we are able to have more flexibility in
10 developing those models.

11 CHAIRMAN WALLIS: Well, does liquid films,
12 are liquid films measured in the Penn State
13 experiment?

14 DR. BAJOREK: No.

15 CHAIRMAN WALLIS: But if you need to
16 somehow coordinate the experiment with the model --

17 DR. BAJOREK: Not -- well --

18 CHAIRMAN WALLIS: You need to measure the
19 things that are in your model.

20 DR. BAJOREK: But I need to have the
21 droplet field so I can break it up as I go through
22 grids.

23 CHAIRMAN WALLIS: So there is also a
24 liquid on the wall, maybe there isn't a liquid on the
25 wall in that --

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1 DR. BAJOREK: It depends on the regime.
2 The low temperature regimes, yes. But --

3 DR. RANSOM: Steve, I think one thing you
4 just mentioned, at least in my experience has been the
5 root of the problem, is the transition boiling regime.
6 Never been able to explain the precursory cooling that
7 takes place.

8 And I'm talking about a macroscopic
9 effect, because these nodes tend to be on the order of
10 half a foot to a foot. So you've got to explain the
11 average heat transfer behavior over that kind of
12 region of the fuel, in order to explain the progress,
13 say, of a quench front, either boiling down, or
14 heating up.

15 I think boil down is easier, but the
16 reflood part has always been harder. So I guess what
17 we ought to look for is how are you going to shed
18 light on that transition boiling regime in the
19 vicinity of the quench front.

20 And while I'm talking, I guess, I would be
21 surprised if even the principal investigator wouldn't
22 prefer a separate effects experiment, where he could
23 get more detail on what is going on, right in the
24 region of that quench front, rather than, say, rod
25 bundle time.

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1 DR. BAJOREK: In fact, as part of the
2 Thermal-Hydraulic Institute we are proposing to do a
3 test very much like that.

4 DR. RANSOM: In this facility, or?

5 DR. BAJOREK: Not in this facility, but to
6 use a smaller, separate effects facility where you can
7 focus on some of the details, and use what you learn
8 there in conjunction with the rod bundle, to come up
9 with better models.

10 DR. RANSOM: That has a better chance of
11 finding the answer, I would think.

12 DR. BAJOREK: I mean, in a way we are
13 looking at some of the details of the quench front in
14 much the way that the program was structured at UCLA
15 for subcooled boiling, where he had small scale
16 experiments to take a look at how the bubbles form,
17 and developed, versus subcooling and flow on a flat
18 plate.

19 Very easy geometry, easy to photograph,
20 easy to measure, and then use a small rod bundle to
21 verify things. So we are thinking in terms of that.

22 DR. SANJOY: There's been an enormous
23 amount of work done at that scale in tubes and simple
24 geometries. So we don't want to, we want to make sure
25 that this is not just repeated in some sense.

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1 Because even the inverted annular regime
2 there has been modeling at Berkley, certainly, there
3 has been extensive set of experiments. I would like
4 to know, exactly, before we launch into this, what it
5 is that we will learn, compared to what it is that we
6 already know.

7 Because I think that the modeling efforts
8 have really not taken into account a lot of these old
9 experiments, where very detailed measurements were
10 made. I can probably give you my thesis on that.

11 MR. SCHROCK: So my question may be, is
12 the past inadequacy of code predictions for this
13 portion of transients a consequence of the structure
14 of the code, or inherent lack of experimental basis
15 for the fundamental processes?

16 If you've not taken the data from past
17 experiments to look at the phenomena processes that
18 are involved there, sufficiently, you may not have
19 used them adequately to know whether you need new
20 experiments, or whether you can gleam that information
21 from the old ones.

22 So it is unclear to me, still, how the
23 motivation occurred originally, and what the vision is
24 for a new set of experiments that are going to fill in
25 the inadequacy of the past work.

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1 DR. BAJOREK: Let me take that as an
2 action.

3 CHAIRMAN WALLIS: Maybe you can think
4 about it. I was just going to propose that we hear
5 from Larry Hochreiter, and then you come back. You
6 were asked to come back at the end of the day, anyway,
7 and you can tell us what you've learned.

8 I mean, they've done these 32 tests in
9 reflow, what did they learn which enlightened you,
10 from those tests?

11 DR. BAJOREK: Well, I will let Larry show
12 the movie, and hopefully --

13 CHAIRMAN WALLIS: Well, that is very
14 qualitative, isn't it?

15 DR. BAJOREK: Well, that part of it.

16 CHAIRMAN WALLIS: Well, I would like to
17 see, actually, since they must be far enough into the
18 program, where you could say, you know, this was the
19 state of the art before they did the tests, and this
20 is what we've learned so far, and this is an advance
21 in something.

22 DR. BAJOREK: Well, I will let Larry show
23 the movie. But I think one of the very eye opening
24 things is what are first order effects in these
25 experiments, versus what may not be as, you know, as

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1 important.

2 I think we will see the grid effects --

3 CHAIRMAN WALLIS: Ideally we ought to have
4 some measure of uncertainty before, and uncertainty
5 after, and how you've reduced the uncertainty by
6 getting more information.

7 DR. MOODY: A minute ago the subject came
8 up separate effects test, and I was looking at the
9 abstract of this. Maybe I missed something, the
10 report describes, so on, and so on, to conduct a
11 systematic separate effects test.

12 Well, that is what has been done here, is
13 being done, right?

14 DR. BAJOREK: Right.

15 DR. MOODY: These are separate effects?

16 DR. BAJOREK: Yes.

17 DR. RANSOM: Distinguished from an entire
18 system, but still it is a rod bundle test, which --
19 and you are looking at things, I think, that are
20 occurring locally.

21 So, yes, it is separate effects, and it is
22 a single bundle.

23 DR. MOODY: Would it be system boundaries?

24 DR. BAJOREK: Large separate effects test,
25 and small separate effects test.

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1 CHAIRMAN WALLIS: Would it be time to go
2 on to the Penn State presentation and then you can
3 come back later?

4 DR. BAJOREK: Yes.

5 CHAIRMAN WALLIS: And perhaps give us a
6 bit more wisdom on what you've learned from it all.

7 DR. SANJOY: Before you go, Steve, just a
8 question. You said three fields. And if I recall,
9 there was three fields in track way back, at some
10 point.

11 DR. BAJOREK: There was one version where
12 they did have three fields. I'm not sure whatever
13 became of that.

14 DR. SANJOY: I mean, I think Tony Hurt put
15 it in -- and Kenneth Sly. Oh, Ken Williams, okay.
16 What happened to that?

17 DR. HOCHREITER: It got published as a
18 thesis.

19 DR. SANJOY: It was never put in?

20 DR. BAJOREK: COBRA/TF has just the two
21 fields, but part of our vision is to get that third
22 field in there, to make it behave a lot more like
23 COBRA/TF.

24 DR. HOCHREITER: Larry Hochreiter, from
25 Penn State.

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1 The first thing I learned is don't go
2 second or third at an ACRS meeting. What I wanted to
3 do was to show you some of the results that we've
4 gotten to date, in the program.

5 The comments that, I think, Dr. Schrock
6 made, and Dr. Wallis made, about the program, the
7 genesis, the origin, the goals, and this type of
8 thing, we did present this to the committee, but it
9 has been a couple of years.

10 MR. BOEHNERT: Yes, you did make a
11 presentation.

12 DR. HOCHREITER: And I think there was, I
13 know there was at least one, maybe two presentations
14 that Joe Kelly and I did to the Committee, when we
15 were designing the experiment, and basically providing
16 the rationale for why we were going to do these types
17 of test, and what new information we were going to
18 get, what information was lacking, and what
19 information this facility, these tests would provide,
20 that would fill that gap.

21 So as I go through my presentation I will
22 try to point out those areas, okay?

23 This is a joint NRC Penn State program
24 that is being performed at Penn State. The contract
25 was initiated in November of '97. Again, at Penn

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1 State it is a program between the College of
2 Engineering, and the Applied Research Laboratory.

3 The principal investigators are myself,
4 Dr. Bill Cheung, and Dr. Thomas Lin. Dr. Lin works at
5 the Applied Research Laboratory.

6 Again, the reason for doing this through
7 Penn State, at the Applied Research Laboratory, is
8 they have a very good infrastructure for performing
9 experiments. They do, primarily, work for the Navy,
10 and this type of stuff. So they have a very good
11 experimental infrastructure.

12 Now, in terms of background, and of course
13 you have seen all this, what we are primarily
14 concerned about is a loss of coolant accident, and
15 primarily the reflood portion of the loss of coolant
16 accident.

17 And the driving force for it was the
18 improvement in the Best Estimate models. When CSAU
19 came about, and was used, the types of powers that
20 were being examined from the best estimate point of
21 view, were actually fairly low.

22 In the CSAU study I think the peak
23 kilowatts were something around 9. Right now plants
24 are being licensed with the best estimate methodology
25 with the peak kilowatts per foot someplace around 15.

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1 So what has occurred, in the interim, is
2 that the margin that was identified, from the best
3 estimate analysis has basically been consumed by the
4 utility to basically broaden the operating envelope
5 for the plants.

6 And so you are now seeing best estimate
7 peak cladding temperatures that are in the same range
8 of the appendix K calculations that we were looking
9 at, perhaps, five years ago.

10 So now the emphasis on the accuracy of the
11 best estimate method becomes much more of a critical
12 item, because you now have a reduced amount of margin
13 because you have consumed the margin in the analysis.

14 Again, the reflood is usually the period
15 of interest, because this is where the peak cladding
16 temperature occurs. The heat transfer rates are the
17 lowest. I think, as Dr. Ransom indicated, predicting
18 the precursory cooling is the key item here, because
19 this is where the peak cladding temperature is
20 occurring.

21 And you have several different heat
22 transfer mechanisms. And I will show a figure on
23 that. The area that we are looking at, and trying to
24 concentrate, primarily in this program, is a highly
25 dispersed non-equilibrium flow, where we have

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1 superheated steam with entrained liquid droplets,
2 which are at the saturation temperature.

3 The quench front is progressing up the
4 rods, but this takes time. In the meantime the
5 cladding temperatures can continue to heat if you
6 don't predict the heat transfer rates accurately.

7 And so your peak cladding temperatures,
8 even for your best estimate models occur during
9 reflood in nearly all these situations.

10 This is just a schematic of what we are
11 talking about, for a flow regime, where we have
12 basically a quench front moving up, and typically the
13 cases we are looking at you have low injection flow,
14 or flooding rate, so there can be boiling below the
15 quench front.

16 The heat release from the rods generates
17 high steam velocities which basically shear and
18 entrain the liquid, it gets carried up in the rod
19 bundle.

20 CHAIRMAN WALLIS: That blue stuff is
21 liquid?

22 DR. HOCHREITER: Yes.

23 CHAIRMAN WALLIS: I don't see the film
24 boiling.

25 DR. HOCHREITER: Well, I tried to stay

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1 within the lines when I colored it, and it is probably
2 buried behind these tons of liquid here.

3 But you are right, in this case, where low
4 flooding rate, there is a very, very short area of
5 inverted annular film boiling. In facility, you could
6 argue that it is really not even inverted annular film
7 boiling, because it depends on the void fraction that
8 is occurring in here.

9 But the point of interest is actually
10 further up in the rod bundle, where you are basically
11 being cooled by steam, with drops. And it is the
12 interaction between the steam and the drops that is
13 providing cooling.

14 DR. RANSOM: Are your experiments
15 exploring the different reflood rates?

16 DR. HOCHREITER: Yes.

17 DR. RANSOM: Are your experiments
18 simulating different reflood rates all the way from
19 the low to the --

20 DR. HOCHREITER: Yes. I will show you a
21 table of conditions.

22 DR. KRESS: Are they also simulating,
23 right here, an initial temperature of the rods?

24 DR. HOCHREITER: Yes, but we have -- there
25 is, obviously, a range of initial temperatures.

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1 DR. KRESS: Yes.

2 DR. HOCHREITER: We have chosen to keep
3 the initial temperatures lower than what you might
4 find in calculations. The calculated temperatures at
5 the beginning of reflood can be as high as 1,600
6 degrees fahrenheit.

7 We have been started our tests at 14. We
8 have also -- can I defer that until I show you the
9 table?

10 DR. KRESS: Sure.

11 DR. HOCHREITER: The dispersed flow of
12 film boiling region is the region that we are trying
13 to focus on to get better quality data. This is one
14 region, the quench front is the other region.

15 And there are several different heat
16 transfer mechanisms that can occur in this region, and
17 looking at the different models in the computer codes,
18 the codes try to predict all of this in one area or
19 another.

20 The problem is that some of the models
21 will overpredict a particular phenomena, other models
22 will underpredict the phenomena. And so if you get
23 the right answer you are never really too sure of why
24 you got the right answer, other than you might have
25 been lucky that day, okay?

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1 So as Steve had indicated, what we were
2 trying to do in these experiments, we will run the
3 reflood heat transfer experiments, but then we will
4 also do steam cooling, and drop an injection
5 experiments.

6 We are really trying to decompose the
7 disperse flow of film boiling, period, experimentally,
8 and look at these different effects as best as we can.

9 CHAIRMAN WALLIS: What is disperse flow
10 film boiling?

11 DR. HOCHREITER: It is a continuous steam
12 phase which is superheated with dispersed liquid
13 droplets, which are at the situation --

14 CHAIRMAN WALLIS: Why is it film boiling?

15 DR. HOCHREITER: It is film because you
16 have vapor against the wall.

17 CHAIRMAN WALLIS: The droplets don't hit
18 the wall?

19 DR. HOCHREITER: The droplets don't hit
20 the wall.

21 DR. KRESS: That is the important regime,
22 because that is what you have when you get close, most
23 of the way up to the peak clad temperature.

24 DR. HOCHREITER: Right.

25 DR. KRESS: Now, it seems to me like one

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1 could make some real good analytical estimates of each
2 one of these.

3 DR. HOCHREITER: That is right.

4 DR. KRESS: And, you know, the problem I
5 had with it is how many droplets do I have in there,
6 and what is their size.

7 DR. HOCHREITER: Exactly.

8 DR. KRESS: And I made some calculations
9 at one time, this is like 15 or 20 years ago, and I
10 seem to remember that what governed was just two
11 little things, the heat transfer between the vapor and
12 the wall, and the heat transfer between the liquids
13 and the vapors.

14 And I forgot, the radiation just didn't
15 enter into it very much.

16 DR. HOCHREITER: It is small.

17 DR. KRESS: And so if I could, again,
18 handle on those two things, and then basically it is
19 boil down to what is the droplet size and
20 distribution, and how much is in there, because you
21 could almost use existing correlations for that heat
22 transfer between the droplets and the vapor.

23 And almost existing correlations between
24 the vapor and the wall.

25 DR. HOCHREITER: Well, I think it is a

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1 little more complicated than that, because of things
2 like this.

3 DR. KRESS: Well, yes, what happened was,
4 that was -- you are right. The crux of it was that
5 droplet size, and size distribution, and the amount in
6 there changed every time you passed the grid.

7 DR. HOCHREITER: That is right.

8 DR. KRESS: And you never knew how to deal
9 with that.

10 DR. HOCHREITER: The test at Oakridge
11 clearly showed that --

12 DR. KRESS: Yes, and that is what I was
13 looking at, the Oakridge test.

14 MR. SCHROCK: But you say that the codes
15 try to solve this problem, but then you point out that
16 the grid spacer is a complication. The calculation in
17 the code has axial nodes that are probably too large
18 to deal with the detail that you are talking about
19 here.

20 So it is unclear what one means when one
21 says that the code tries to address this level of the
22 physics, it is not possible in an axial node that has
23 a lot of variation from end of it to the other, to
24 deal at this kind of level.

25 So this is what I mean by identifying

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1 where is the difficulty, is it the structure of the
2 code, is it the quality and extent of the experimental
3 information?

4 I'm convinced that it is the latter. I
5 think that it is, somehow, the code and the existing
6 data developed somewhat independently, and so they
7 don't mesh well, and it is hard to use the existing
8 data in the framework of existing codes.

9 So one can change the structure of the
10 code, one can find other experiments that might fit
11 the structure of the code better than the existing
12 ones. But I think you have to define what your
13 objective is, what are you going to do in the end.

14 I don't think you can have a successful
15 resolution of this by getting more detailed
16 experimental data that are beyond the capability of
17 the code to properly utilize those data.

18 DR. HOCHREITER: Yes, but I think you
19 could use the experimental data to tell you what the
20 code should do, and what level of detail you might
21 have to put into the code if you want to represent the
22 phenomena correctly.

23 MR. SCHROCK: I think you can judge that
24 from the data and the code that you already have.

25 DR. HOCHREITER: It depends on the data,

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1 okay? If there were no spacer grids in these, or the
2 spacer grid effect was very, very small, you probably
3 could survive with larger nodes.

4 But what I'm going to show you today is
5 that you are probably going to have to go to finer
6 nodes. Because the spacers you have not is --

7 DR. RANSOM: Well, most of the codes do
8 have a fine mesh rezoning in the conductors, at least.

9 DR. HOCHREITER: But that is at the quench
10 front, primarily, following it.

11 DR. RANSOM: Right. And it seems like the
12 main mechanism that is missing is the bottom one that
13 you have on the slide. And I think I just heard you
14 say that one doesn't occur.

15 DR. HOCHREITER: No, I didn't say that.

16 DR. RANSOM: That the liquid can't touch
17 the wall.

18 DR. HOCHREITER: In the area where the PCT
19 is occurring the liquid does not touch the wall. AS
20 the temperature drops to the point where you can have
21 contact, that obviously does occur.

22 DR. RANSOM: Right, but it seemed to me
23 there was some mechanism in which there is enhanced
24 heat transfer near the quench front, that must be tied
25 up with liquid --

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1 DR. HOCHREITER: Well, I don't --

2 DR. RANSOM: -- contacting the wall.

3 DR. HOCHREITER: -- disagree with you at
4 all, at all. In fact, one of the things that we tried
5 to do in the program is we have faster data sampling
6 rates so we can get the quench more accurately, when
7 the rods do quench, and we have fine zones of delta P
8 cells so we can get an estimate of the void fraction,
9 when the rods are quenching.

10 DR. KRESS: I think that is the important
11 parameter, you need to know how much liquid gets into
12 the system, and that is the importance of that quench
13 front.

14 DR. HOCHREITER: But the quench front,
15 quench front is like a boundary condition, all right?
16 Because it provides the basis for the entrainment,
17 which is swept to the upper elevations.

18 The PCT that you are concerned about is at
19 the upper elevations. So you need to know the history
20 of the generation of the entrainment. In fact, in
21 discussions with Steve, and Joe Kelly, and other
22 people, and even when we did this at Westinghouse, the
23 largest uncertainty in our calculations was the
24 entrainment.

25 Not only the amount of entrainment, and

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1 then what it looks like in the flow. And what we've
2 tried to do in these experiments is to capture that
3 information as accurately as we can.

4 We put collection systems onto the
5 facility to give us a rapid indication of when we get
6 entrainment, how much entrainment we get, and then we
7 have very fine delta P cells across the bundle to
8 indicate what the mass storage is, in the facility, as
9 a function of time.

10 And for most of the tests we converge and
11 get about a five percent uncertainty in the mass and
12 balance. For a test that lasts 1,000 seconds, which
13 is pretty good, I think.

14 But this is a phenomena that is more
15 prevalent at the quench front, whereas just these
16 phenomena are more prevalent further up into the
17 bundle.

18 And, as I said, if you did not have spacer
19 grids, you probably could get away with coarser
20 noding. But when you put in something like this, the
21 changes dramatically, I think it is dramatic, anyways.

22 The flow behavior, the dispersed flow
23 behavior, then I think you will have to go to finer
24 axial nodes as, I think, you were suggesting. We did
25 a bunch of noding sensitivity calculations with

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1 COBRA/TF, at Penn State, when we were trying to
2 predict these types of tests.

3 Because we would do pretest predictions
4 for every test, as the cost of the rod bundle is
5 outrageous. And we certainly don't want to burn out
6 any rods. The program that Steve shows there goes out
7 for another three or four years, and there is no
8 provisions to rebuild a rod bundle.

9 And this rod bundle costs a half a million
10 dollars. So we do not want to burn up any rods. So
11 we would do tests and calculations until the cows came
12 home. And this is part of the reason why we set a
13 lower initial temperature.

14 But there are other reasons that make
15 these tests different, and I think, give you better
16 information than what exists today.

17 This is the test facility, basically. And
18 I have to --

19 DR. KRESS: Theron, he needs his mobile
20 microphone.

21 DR. HOCHREITER: If I don't move around I
22 fall asleep.

23 MR. SCHROCK: This last picture doesn't
24 look much --

25 DR. HOCHREITER: I'm sorry?

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1 MR. SCHROCK: This las picture doesn't
2 look much like your low reflood rate cartoon on the
3 previous one.

4 DR. HOCHREITER: Well, this is a bunch of
5 pipes and tanks.

6 MR. SCHROCK: I'm not on this one yet.
7 Your mechanistic diagram, and your low reflood rate.

8 DR. HOCHREITER: This is a blowup of --

9 CHAIRMAN WALLIS: Larry, don't touch the
10 screen.

11 MR. BOEHNERT: Don't mark on the screen,
12 only Tom can do that.

13 (Laughter.)

14 DR. HOCHREITER: This picture would be
15 occurring up in here.

16 MR. SCHROCK: And your focus is mainly on
17 that region, in your experiments?

18 DR. HOCHREITER: Well, we have provided
19 instrumentation to focus on this region, but we've
20 also provided more detailed instrumentation to focus
21 on this region. We tried to cover the transient.

22 Not only low flooding rates, but high
23 flooding rates.

24 MR. SCHROCK: Well, I'm recalling some
25 earlier experiments which showed, as this picture

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1 suggests, a sort of tongue of liquid moving up and
2 breaking off, having enough momentum to rise some
3 distance beyond the point where it is broken off, but
4 it doesn't have enough force left acting on it to
5 carry it on up, so it falls back.

6 And so you have liquid being thrown ahead
7 and falling back, thrown ahead and falling back. It
8 has always seemed to me that that is, inevitably,
9 important in getting at entrainment rates.

10 Is that going to be studied in these
11 tests?

12 DR. HOCHREITER: Actually if you -- this
13 region can be between eight inches and a foot above
14 quench front. It is the low void fraction region,
15 lower void fraction region.

16 And what we did, in the experiment, and
17 you will see a picture of this, is that we have
18 pressure cells every three inches. So as the quench
19 front, and it is over about three feet, if I remember
20 correctly.

21 So as the quench front enters that region
22 we will get a finer definition of the local void
23 fraction. We also set the rod instrumentation up such
24 that within each void fraction cell range we would put
25 thermacouples in the rods that would be approximately

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1 in the center of the region of where you would be
2 measuring the void fraction.

3 Because the cell is going to measure the
4 average void fraction, once you correct it for
5 pressure drop, and so forth.

6 MR. SCHROCK: So over some period of time,
7 as well as space?

8 DR. HOCHREITER: That is correct.

9 MR. SCHROCK: And time is large compared
10 to the periods of oscillation that I've described, I
11 think?

12 DR. HOCHREITER: Yes, because these
13 experiments, I might as well say this now, one of the
14 unique things we did in these experiments was we kept
15 the power constant. In nearly all the other reflood
16 experiments they simulated a K power.

17 That makes it more prototypical. Our
18 objective was not to be as prototypical as those
19 previous experiments, but rather to provide us data,
20 better quality data, that we could use for model
21 development and assessment.

22 And by keeping the power constant you
23 basically stretch out, particularly, the dispersed
24 flow film boiling period, you stretch the entire
25 experiment out, for that matter.

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1 So you get, basically, quasi-steady state
2 disperse flow film boiling. Now, it is not perfectly
3 steady state because the quench front is slowly
4 advancing up into the bundle.

5 But you get a longer period of quasi-
6 steady state where you can make measurements of vapor
7 temperature, drop sizes, rod temperatures, and with
8 the delta P cells in for a void fraction.

9 In addition to the mass that is carried
10 out of the facility, measure the steam flow that is
11 carried out, we measure the liquid flow that is
12 carried out.

13 DR. SANJOY: But you have a power profile,
14 don't you?

15 DR. HOCHREITER: We have an axial power
16 profile, but we kept it simple.

17 DR. SANJOY: But it was sort of peaked, if
18 I remember?

19 DR. HOCHREITER: Right, at about the ten
20 foot elevation.

21 DR. SANJOY: So, in fact, you've got
22 something prototypical about that?

23 DR. HOCHREITER: Yes.

24 DR. SANJOY: If you had kept it uniform,
25 that would have made more sense to --

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1 DR. HOCHREITER: No, we debated that, and
2 it just -- we looked at a bunch of profiles that were
3 being used for best estimate analysis, and the worst
4 answers you get, in the best estimate code, are for
5 profiles where the peak is above the mid plain.

6 And it is simple logic, because you are
7 just further from the quench front.

8 DR. SANJOY: But from the viewpoint of
9 what you are saying right now, which is to get data
10 which is for model building, you know, and keep the
11 quasi-steady approach, and so on, that won't give you
12 a quasi-steady approach.

13 DR. HOCHREITER: Well, we do get a quasi-
14 steady approach.

15 DR. SANJOY: Because the power is going
16 up, right?

17 DR. HOCHREITER: The local in your power
18 is going up, but the temperature response are almost
19 steady with time. I will show you some of the
20 temperatures.

21 DR. SANJOY: Well, let me get back to the
22 void fraction measurements. You said you corrected
23 for pressure drop, and so on? How do you do that?

24 DR. HOCHREITER: We do a mass energy, we
25 are doing this now, we are doing the calculations now.

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1 We know the exit flow rates, we measure those. We
2 know the vapor temperatures in the bundle, so we know
3 the degree of non-equilibrium.

4 We know the rod heat flux distribution
5 from the thermacouples in the heater rods. We can
6 back calculate down into the bundle the local quality,
7 real quality. So we can calculate the local steam
8 flow, the local liquid flow.

9 DR. SANJOY: Equilibrium quality?

10 DR. HOCHREITER: Non-equilibrium, because
11 we are using a measured vapor temperature. Based on
12 that we can estimate a frictional pressure drop for
13 the cells, and correct the cells.

14 Now, the correction will be the most
15 inaccurate for the highest void fractions. The
16 correction will be more accurate for lower void
17 fractions, but the effect of the correction for lower
18 void fractions is less important, because the
19 elevation then is more dominant.

20 DR. SANJOY: How much is the correction?

21 DR. HOCHREITER: We haven't gotten to that
22 point yet. We are just getting to that point now.
23 But in previous, I've done this before, in other
24 tests, but in a much, much coarser scale, and it was
25 approximately a 10 percent effect.

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1 DR. SANJOY: And you have accelerational
2 pressure drops, too?

3 DR. HOCHREITER: Yes, that is accounted
4 for. All three pressure drop components.

5 CHAIRMAN WALLIS: Now, in the region where
6 globes of liquid are going up and falling down again,
7 they follow $F=MA$, and gravity acts on them, but it
8 doesn't create any pressure drop, the acceleration and
9 deceleration of the masses of liquid is completely
10 balanced, or mostly balanced by gravity.

11 So the usual kind of decomposition into
12 gravitational and frictional doesn't work.

13 DR. HOCHREITER: Let me think about that.

14 CHAIRMAN WALLIS: If you just juggle it,
15 tossing balls in the air, they go round, and round,
16 and round, there is no pressure drop from the juggling
17 the balls.

18 DR. HOCHREITER: I understand what you are
19 saying, and I went through that argument. And somehow
20 I convinced myself that the cell would measure this.
21 Now, maybe I better go back and --

22 CHAIRMAN WALLIS: -- acceleration terms
23 for the --

24 DR. HOCHREITER: Well, there is an
25 acceleration term.

1 CHAIRMAN WALLIS: But it is not the
2 average acceleration, they go up and they come down
3 again.

4 DR. HOCHREITER: If it is a -- no, local
5 effects like that we are, obviously, not going to get.
6 Because, first of all, the cell is going to measure
7 the average across the bundle.

8 And we have to do, like Dr. Schrock says,
9 you will have to look at that in time, in addition to
10 space.

11 CHAIRMAN WALLIS: You don't have
12 independent void fraction by means of gammas, do you
13 have some sort of a --

14 DR. HOCHREITER: We talked about that in
15 the program, and because of funding constraints, that
16 was never --

17 DR. SANJOY: The idea could be, at least,
18 checked against people who are using gamma
19 densitometers and bundles and see how accurate it is.

20 DR. HOCHREITER: There was a report on
21 that, I think, in the FIST program.

22 DR. SANJOY: Well, they are using it in
23 Costine, the densitometers. Franz Manger has done
24 some work, so you could probably check it out, at
25 least, to see whether it is accurate or not.

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1 We always felt it wasn't. We made a lot
2 of gamma densitometer measurements with tubes around
3 the reflood point, one of my students did this way
4 back in the '80s. And we never felt comfortable with
5 pressure drops.

6 But maybe you've worked out how to do it,
7 I don't know.

8 DR. HOCHREITER: Well, it depends upon the
9 sensitivity of the cell. These are actually very
10 sensitive cells.

11 DR. SANJOY: Right, very small pressure
12 differences.

13 MR. SCHROCK: In your report you describe
14 some commercial instrumentation which has outstanding
15 accuracy.

16 DR. HOCHREITER: For the cells?

17 MR. SCHROCK: No, no, for a number of
18 different kinds of instrumentation that I couldn't
19 tell you, off the top of my head, without looking back
20 at the report, which one I'm thinking of.

21 But you give a single figure for the
22 accuracy of that instrumentation, which is a
23 manufacturer's claim.

24 DR. HOCHREITER: That is right.

25 MR. SCHROCK: Do you have any independent

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1 corroboration of the manufacturer's claim, and do you
2 have a reason to believe that the uncertainty is not
3 a function of the scale?

4 DR. HOCHREITER: Okay, that is four
5 questions.

6 MR. SCHROCK: That is okay, that is all
7 related.

8 DR. HOCHREITER: Actually we've discussed
9 this with the NRC. To me what you get from the
10 manufacturer would be the minimum error.

11 MR. SCHROCK: I saw that that is the way
12 you are referring to it, I don't understand why it is
13 minimum, but --

14 DR. HOCHREITER: I'm sorry maybe it is a
15 maximum error, maximum error. And we just went
16 through this for the data report where this is Ralph
17 Rosal in the back, and he looked at the trace of the
18 signal from the instrument through the electronics,
19 through the DAS system, and so forth, and you get a
20 most probable error.

21 And that is based on the manufacturing
22 information. So that is absolutely the absolute best
23 it could ever, ever be. And that is an error, okay?
24 The uncertainty due to the flow of conditions, the
25 pressure, the pressure variation, these are usually

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1 much larger.

2 And we have to get that information by
3 looking at the experiment, and it is larger. So when
4 you design the experiment you try to design the
5 instrumentation to minimize Any errors or uncertainty
6 in the instrumentation.

7 But there is an additional component, if
8 you really want the answer, that you have to add on to
9 it, which reflects the uncertainty in the experience.

10 MR. SCHROCK: Well, I guess my comment and
11 question was motivated by a couple of things. One is
12 an inherent distrust of manufacturer's claims for the
13 accuracy of instruments that are black boxes. Buy my
14 instrument, plug it in, and get this accuracy of
15 measurement. It is not a sound engineering approach.

16 Secondly --

17 DR. HOCHREITER: Wait a minute, let me
18 address that. To address that we calibrate.

19 MR. SCHROCK: Well, that is why I asked if
20 you have an independent corroboration of that level of
21 accuracy.

22 The other point is that in almost every
23 case, when one looks at the accuracy of the
24 instrument, the accuracy of a given reading, that
25 accuracy will depend upon whether it is at full scale,

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1 near full scale, half scale, a tenth scale, or
2 whatever.

3 And when one reads the report one has the
4 impression that you've not considered the issue of the
5 accuracy of your experimental measurement in terms of
6 where in the full scale you are operating.

7 DR. HOCHREITER: That is probably true.

8 MR. SCHROCK: We can come back to it -- I
9 mean, it is true you have not?

10 DR. HOCHREITER: We considered the range
11 that it has to cover, but I think when we did the
12 uncertainty assessment for estimate we did not
13 consider, as far as I remember, I don't think we
14 considered -- I don't think we considered where we
15 were in the range, I'm not sure, it has been so long
16 since we wrote that.

17 CHAIRMAN WALLIS: Do we need to move on to
18 your pipes and tanks?

19 DR. HOCHREITER: Pipes and tanks.

20 DR. RANSOM: May I just suggest one thing?
21 You know, as far as this void fraction question,
22 measuring with hydrostatic pressures, it can be
23 answered with your code, because it does include all
24 the forces that are involved.

25 DR. HOCHREITER: That is correct.

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1 DR. RANSOM: And --

2 DR. SANJOY: Not for falling back.

3 DR. RANSOM: Pardon?

4 DR. SANJOY: Not really, because what you
5 see in these experiments, I don't know if you ever --

6 DR. RANSOM: Well, I'm not saying
7 everything, but the hydrostatic pressure is affected
8 by the transfer of the body force on the liquid, to
9 the vapor, through the interfacial drag, that is the
10 mechanism that actually changes the hydrostatic
11 pressure along the tube.

12 DR. SANJOY: But the flow is oscillating,
13 remember, in this. And it is not linear with the
14 velocity difference. So when you have a non-linearity
15 like that, it doesn't balance, exactly what Graham was
16 saying.

17 DR. RANSOM: Well, my main point was that
18 it won't answer the question on your experiment. But
19 if you go look at a code, you know what the void
20 fraction is, and you know what the void fraction is
21 that you would calculate from the hydrostatic pressure
22 change.

23 CHAIRMAN WALLIS: As long as the average
24 is representative of what is happening.

25 DR. HOCHREITER: Exactly, it would have to

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1 be the average, and I think it would be better to look
2 at the actual pressure drop, rather than the void
3 fraction, which is inferred.

4 DR. RANSOM: Well, you have two things.
5 I mean, you take the pressure drop, you calculate,
6 convert it to a void fraction, and you can look at the
7 void fraction, which is --

8 DR. SANJOY: You are trying to balance the
9 code against the experience, directly.

10 DR. RANSOM: No, I mainly want to do an
11 experiment with the code and say, okay, how does the
12 real void fraction compare with what I would calculate
13 from, say, a hydrostatic pressure change in the vapor
14 field, and how big is that difference. That can be
15 done.

16 Without knowing anything about the
17 experience, it just tells you what kind of errors you
18 might expect.

19 CHAIRMAN WALLIS: Sometimes the liquid is
20 running down the wall, and you actually have a
21 negative friction in your theory, which is --

22 DR. RANSOM: That doesn't affect -- that
23 affects the hydrostatic pressure, also, because it
24 tends to resist the, you know, the vapor flow.

25 DR. SANJOY: Well, the code is based on a

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1 model.

2 DR. RANSOM: Yes.

3 DR. SANJOY: The model actually, when you
4 average the equations, the way they are done, only
5 holds if the oscillations are not large compared to
6 the mean flow.

7 You can show, in fact, that the model
8 breaks down because friction is non-linear, because of
9 the square. So these mean field models that are used
10 don't use for oscillatory flows very well. I mean,
11 this is pretty well known.

12 DR. RANSOM: Because of virtual mass
13 effects, and things like that.

14 DR. SANJOY: Well, not even that, it just
15 comes through friction, I mean, directly. It is a
16 non-linear term, right?

17 CHAIRMAN WALLIS: Well, I guess we are not
18 going to discuss the model at all, today. I think we
19 should move on to the experiment.

20 DR. SANJOY: That is why I'm saying the
21 model may not be -- it would be nice if you took a
22 densitometer and do it.

23 CHAIRMAN WALLIS: He is not making a
24 presentation on the model, so I guess we have to ask
25 him about his experiment.

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1 DR. HOCHREITER: This is the test section,
2 here, these are the delta P cells that are hung off
3 the test section. And, again, there is a fine, fine
4 group of cells in this region here, to capture the
5 quench front effects, particularly in attempt to
6 correlate heat transfer with void fraction.

7 The objective was to get a set of data,
8 better data than exists right now, because most of the
9 experiments right now, these things are at least a
10 foot to two feet apart. So the objective is to get a
11 better set of data where you can correlate the as-
12 measured heat transfer, versus void fraction.

13 So you can come up with a relationship
14 between heat transfer and void fraction, particularly
15 in the region above the quench front.

16 DR. MOODY: Where on that background is
17 your peak?

18 DR. HOCHREITER: Right about here.

19 CHAIRMAN WALLIS: But the only unusual
20 feature of this system is the pressure oscillation
21 dampening time.

22 DR. HOCHREITER: Yes.

23 CHAIRMAN WALLIS: It seems to me that in
24 the real reactor you have a compliance of the system,
25 it is not clear to me that the pressure oscillation

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1 damping tank is prototypical of that compliance,
2 whether or not you get oscillations in reflood is
3 related to the whole system.

4 DR. HOCHREITER: Well, we weren't trying
5 to be prototypical here. What we wanted to be able to
6 do is control the pressure more accurately,
7 particularly in here.

8 CHAIRMAN WALLIS: Yes.

9 DR. HOCHREITER: Because pressure
10 variations, and we found this out because -- I can't
11 find where the valve is. This valve could cycle,
12 would cycle, actually. And you would drive pressure
13 oscillations in here, this result in invalidating a
14 large number of tests, because it was like an imposed
15 boundary condition on the facility.

16 DR. SANJOY: I think your point is well
17 taken, but in a real system, in a prototypical system
18 you could get oscillations, as Graham pointed out,
19 especially in some of these new concepts where the
20 reflood is gravity driven.

21 DR. HOCHREITER: All the reflood in every
22 plant is gravity driven.

23 DR. SANJOY: Right, so then you will get
24 the --

25 DR. HOCHREITER: Yes, but it is the

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1 oscillations that come from the downcomer, because
2 that is where the head is, that is what is driving the
3 flow into the reactor.

4 DR. SANJOY: Right, but in a sense these
5 oscillations depend on the details of the system, and
6 you could get oscillations, right? And they can
7 affect entrainment.

8 DR. HOCHREITER: Oh, they will.

9 DR. SANJOY: Yes.

10 DR. HOCHREITER: I mean, we can simulate
11 that effect in this test.

12 CHAIRMAN WALLIS: Maybe you need to do
13 tests with different amounts of oscillations.

14 DR. HOCHREITER: There have been tests
15 that have been run like that. For instance, we ran
16 some in the FLECHT AND FLECHT SEASET program. We
17 didn't really have a lot of different oscillations.

18 We also ran gravity reflood tests at both
19 those programs. So, I mean, there is some data out
20 there, and you do get these surges that go into the
21 bundle. And then you are dependent upon the driving
22 head, and the resistance downstream.

23 CHAIRMAN WALLIS: I think the surges tend
24 to help your quenching?

25 DR. HOCHREITER: They do. But then the

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1 flow drops out. The flow reverses and drops out, and
2 you are basically heating up adiabatically.

3 CHAIRMAN WALLIS: We don't know what
4 happens in a reactor.

5 DR. HOCHREITER: No. I do remember the
6 Long Sung Tong, that reactors don't oscillate, I do
7 remember that.

8 Anyways, in our test facility we have an
9 upper plenum here, which react as a first stage space
10 separator, and we have liquid collection tanks. And
11 the idea was to quickly measure the liquid as soon as
12 it got up here.

13 So before separation we measure the liquid
14 in a small tank first, then a larger tank.

15 CHAIRMAN WALLIS: -- from your write-up,
16 how would the upper plenum work. You have something
17 about a weir, and trying to make sure there was no
18 back flow from the upper plenum.

19 DR. HOCHREITER: Yes.

20 CHAIRMAN WALLIS: But I couldn't see,
21 there was no detail in the --

22 DR. HOCHREITER: Well, not on this figure,
23 no.

24 CHAIRMAN WALLIS: -- so that geometry,
25 even in your big fat report I couldn't see any detail

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1 of what happened up there.

2 DR. HOCHREITER: This housing extends into
3 the upper plenum. So the liquid that gets separated
4 out here does not run back down. And then you drain
5 it very quickly, and you vent -- these tanks are
6 vented to the plenum.

7 This is a standard steam separator with a
8 liquid collection tank, so any liquid that gets
9 carried out by the steam is separated and measured
10 here. This says, we talked about the suppression
11 damping tank.

12 So the liquid measurements, for the liquid
13 of the bundle are here, here, and here. This is the
14 steam flow, and then these pipes are heated, and these
15 tanks are heated.

16 All this system here is heated saturation.

17 CHAIRMAN WALLIS: How do you know how to
18 slice that damping tank?

19 DR. HOCHREITER: We looked, actually, at
20 the ACHILLES program, and looked at the volume in
21 ACHILLES versus the volume in the tank, and scaled it
22 based on that. Because the ACHILLES had very, very
23 good pressure control.

24 CHAIRMAN WALLIS: The purpose is to damp
25 out oscillation not to --

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1 DR. HOCHREITER: Really, the purpose is to
2 prevent any oscillations that come from trying to
3 control the pressure to feedback under the system. We
4 had this problem in FLECHT SEASET, and we were trying
5 to cure that problem.

6 And ACHILLES did not have that problem,
7 and the ACHILLES people came to Westinghouse and
8 picked our brains for several days. In fact Ralph
9 Rosal went over to England to go through a design
10 review on ACHILLES.

11 And the thing that the British added,
12 which was very different, was this tank. And they
13 wound up with better pressure control than we had in
14 FLECHT SEASET.

15 We also have provisions for a boiler which
16 can provide the single phase steam into the facility.
17 We have an injection port within the housing to be
18 able to inject water droplets of different sizes.
19 We've actually run tests on injection nozzles, and
20 measured the droplet sizes.

21 So we can run experiments now. Those
22 tests where you would have steam coming in here, and
23 you would inject water, would be more of a steady
24 state, or much more of a steady state from boiling
25 test.

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1 Because what you are doing is you are
2 getting rid of the quench front, okay? So in theory
3 you could run those tests for much, much longer period
4 of time, separate out the data.

5 And there is other instrumentation, within
6 the facility, where you can measure more details
7 within the rod bundle themselves. We have traversing
8 steam probes, which I will show you a schematic of,
9 and then pass one around.

10 And when you run a steady state test, like
11 a steam cooling test, you can traverse these steam
12 probes, and there is 13 of them.

13 CHAIRMAN WALLIS: Can you tell us what
14 they actually measure?

15 DR. HOCHREITER: Temperature.

16 CHAIRMAN WALLIS: They measure their own
17 temperature, but how is it related to what is going on
18 around them?

19 DR. HOCHREITER: Well, I'm going to show
20 you some of that.

21 CHAIRMAN WALLIS: -- they quench, so they
22 go down to the saturation temperature.

23 DR. HOCHREITER: And then come back up.

24 CHAIRMAN WALLIS: Come back up. Were they
25 measuring radiation from the rods?

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1 DR. HOCHREITER: There is a radiation
2 component that has to be factored in.

3 DR. KRESS: Now, you can run those tests
4 at a higher temperature, because you don't have to
5 worry about the burn-up.

6 DR. HOCHREITER: Well, you always have to
7 worry about burning up these rods.

8 DR. KRESS: yes, but you don't have to
9 worry about going into the departure from nucleate
10 boiling time.

11 DR. HOCHREITER: No, because you are
12 already there.

13 DR. KRESS: Yes. But you could run them
14 at higher temperatures, I think.

15 DR. HOCHREITER: I will tell you what
16 limits some of the temperatures, are going to be this
17 apparatus up in here.

18 DR. KRESS: You've got limitations on the
19 steam temperature coming in there?

20 DR. HOCHREITER: Right.

21 DR. KRESS: Okay.

22 DR. HOCHREITER: I mean, I think we went
23 to metallic seals, up here, for that very reason.

24 MR. SCHROCK: These droplets that are
25 sprayed in, are sprayed into the rod bundle, how do

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1 you prevent them from impinging directly on the wall?

2 DR. HOCHREITER: We've done some
3 experiments where we've positioned these, and these
4 holes are electromechanically machined, so they are
5 very precise holes. And we inject, into the
6 subchannel center.

7 CHAIRMAN WALLIS: Pointing downstream?

8 DR. HOCHREITER: Well, pointing in the
9 direction of the steam flow, okay? And so we run some
10 bench type experiments on that. Will they impact the
11 walls? I'm not sure.

12 MR. SCHROCK: But it is not directed
13 towards the wall, it is not like a --

14 DR. HOCHREITER: No, no --

15 MR. SCHROCK: -- spray head, they are
16 opposite a lot of different directions, it is one
17 little jet that --

18 DR. HOCHREITER: It is like -- what, three
19 small holes per subchannel, if I remember correctly.

20 MR. SCHROCK: There is three small jet
21 streams axially down each --

22 DR. HOCHREITER: Right, subchannel. And
23 we can, obviously, bury that. We can reduce the
24 number of holes so you reduce the amount of liquid
25 flow.

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1 And these are inserted tubes that slide in
2 between the rods, and with the holes pointing upward.
3 And we have not run any of those tests yet. Those are
4 tests to be run in the future.

5 This is a cross section of the bundle. It
6 is a seven by seven. These are, basically, rods which
7 are hollow tubes, these are not heated. So there is
8 45 heater rods, okay?

9 And when we look at the data we primarily
10 look at the inner 5 by 5. We do have instrumentation,
11 of course, all the way around it, and also on the
12 housing.

13 The rods are made out of inconnel, the
14 housing is made out of inconnel. The thermocouple
15 sheaths inside the heater rods are made out of
16 inconnel.

17 And the reason for this is to try to
18 prevent differential thermal expansion which can lead
19 to bowing, either of the housing, or a bowing of the
20 rods. Inconnel is a better high temperature material
21 to be used, anyways.

22 Inside the bundle we have eight of these
23 spacer grids.

24 CHAIRMAN WALLIS: Now, is there some
25 liquid that goes to the outer wall, and is very

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1 different from the liquid in the middle?

2 DR. HOCHREITER: Well, we try to minimize
3 this access flow area to prevent that. We also heat
4 the housing by radiation from the rods. So when you
5 start the tests, you start the tests full of steam,
6 and then you basically pulse the bundle to heat the
7 housing.

8 And we typically get the housing
9 temperature up to around 900 to 1,000 degrees
10 fahrenheit at the peak power location.

11 And I'm going to show you some housing
12 quench fronts, and some rod quench fronts.

13 DR. MOODY: Is this little flag on each
14 one of these the skin flow?

15 DR. HOCHREITER: Yes, that is a simulation
16 of a prototypical mixing vein grid.

17 Westinghouse was kind enough to send us
18 drawings without dimensions, which that was fine. And
19 then we took those drawings, and we made manufacturing
20 drawings, and we had a company make the grids for us.

21 The supports we have to use are different
22 than what are used in prototypical grids. Plus we
23 have to leave more clearances, okay? When the bundle
24 is cold the rods should rattle, all right?

25 In other words, we don't really use the

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1 grids for anything more than spacing of the rods. In
2 the reactor the grids are really used to support the
3 rods.

4 And the reason for this is we don't want
5 the rods to get bound up in the grids when it is hot.
6 And we don't want the rods to bow.

7 MR. SCHROCK: How do we cope with the
8 problem that the manufacturer's spacers may, probably,
9 be different than the ones that you examine in these
10 experiments?

11 How dependent will your "models" be on the
12 specifics of these spacer geometries?

13 DR. HOCHREITER: Well, what we are
14 planning on doing is we will characterize this grid
15 primarily in terms of a blockage area. Now, we may
16 have to go to a finer level than that, particularly
17 when we are looking at the veins.

18 We have to look at the fraction of the
19 flow that is swept by the veins. But the calculations
20 that I did years and years ago basically say that, you
21 know, the steam can flow around things, the drops go
22 straight through.

23 So I think to the first order of
24 magnitude, the thing that is important is the amount
25 of blockage area, because that is what is going to

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1 shatter the drops.

2 MR. SCHROCK: So if there is no clear line
3 of sight through a grid spacer, the detail of the
4 geometry no longer matters, the liquid is going to
5 impact the wall?

6 DR. HOCHREITER: That is right, that is
7 what I think.

8 MR. SCHROCK: All right.

9 DR. HOCHREITER: This is the test
10 facility. These, again, are all the delta P cells.
11 One of the unique things we did in this facility,
12 which caused us much agony and grief, was to use very
13 large windows.

14 CHAIRMAN WALLIS: Why are those delta P
15 cells so enormous?

16 DR. HOCHREITER: I have no idea. But I
17 will say that we got a good deal on this.

18 DR. SANJOY: Are they Pizio?

19 DR. HOCHREITER: No, strain gauge. I'm
20 looking at Ralph. I think it is strain gauge, the
21 delta P cells, they are strain gauge, aren't they?

22 DR. ROSAL: No.

23 DR. HOCHREITER: What are they?

24 DR. ROSAL: It is a diaphragm.

25 DR. HOCHREITER: All right.

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1 DR. SANJOY: Because it is very sensitive,
2 right?

3 DR. ROSAL: -- the gap between the sensor
4 and the diaphragm, and they are very strong.

5 MR. BOEHNERT: How do they measure that
6 gap?

7 DR. ROSAL: Your question is how do you
8 measure the delta peak?

9 DR. SANJOY: So sensitively, yes.

10 DR. ROSAL: The sensor is a very large
11 diaphragm, and both sides have a, they measure, I
12 guess, the gap, the movement of the diaphragm.

13 DR. SANJOY: Is that a capacitance, or
14 optical --

15 DR. ROSAL: It is like a capacitance
16 detector, and it is very sensitive, it is very strong.
17 You can overload one side, 5,000 PSI, and the
18 diaphragm doesn't disturb.

19 DR. SANJOY: Are you also -- this is not
20 a flash mount, little pressure -- or how is the --

21 DR. ROSAL: The taps are on the housing.

22 DR. SANJOY: So it goes into the wall with
23 a little tap?

24 DR. ROSAL: There is a cavity in the DP
25 cell where the two lines come, the high side and the

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1 low side come in.

2 CHAIRMAN WALLIS: How do you know what is
3 in the lines?

4 DR. HOCHREITER: You probably can't see
5 these, these are all sloped downward.

6 DR. ROSAL: THE lines are tubes, 2/8ths in
7 diameter, they come from the wall of the housing into
8 the --

9 CHAIRMAN WALLIS: They have to be full of
10 liquid to work properly?

11 DR. ROSAL: Yes, there is liquid.

12 DR. HOCHREITER: -- in the reference leg,
13 too.

14 DR. ROSAL: It will maintain the reference
15 leg full all the time.

16 DR. SANJOY: Do you purge liquid through
17 them?

18 DR. ROSAL: Yes.

19 DR. SANJOY: Or how do you keep them full?

20 DR. ROSAL: Yes, you purge.

21 DR. SANJOY: Cold liquid?

22 DR. HOCHREITER: Yes. And the stand-off
23 keeps them cold.

24 DR. ROSAL: They are away from the
25 housing, so that the reference leg is at room

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1 temperature all the time.

2 DR. SANJOY: And does this liquid actually
3 get into the test section?

4 DR. HOCHREITER: You mean the liquid in
5 here?

6 DR. SANJOY: Yes, what happens to the
7 liquid in the lines?

8 DR. HOCHREITER: Well, you start off with
9 these as full as you can get them, okay? But they are
10 sloped towards the cell.

11 DR. ROSAL: There is a slope and the
12 diameter is large enough so we don't capture gas
13 bubbles in it.

14 DR. HOCHREITER: But what you are trying
15 to do, you are trying to always make sure the
16 reference leg on the cell stays filled.

17 DR. SANJOY: Well, each of the taps have
18 to stay filled too, right?

19 DR. HOCHREITER: No.

20 DR. SANJOY: They don't?

21 DR. HOCHREITER: No.

22 DR. SANJOY: Because they are horizontal?

23 DR. HOCHREITER: Yes. Slight slope.

24 DR. SANJOY: And the hole itself is it
25 very carefully deburred, or --

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1 DR. HOCHREITER: Yes.

2 DR. SANJOY: And you've checked it all?

3 DR. HOCHREITER: Yes.

4 DR. MOODY: What was the diameter, Larry,
5 did you say?

6 DR. HOCHREITER: The tubing is 3/8ths of
7 an inch.

8 CHAIRMAN WALLIS: How big is the hole?

9 DR. ROSAL: One-eighth of an inch. From
10 experience we determined that for two phase flow --

11 CHAIRMAN WALLIS: So a bubble in the hole
12 have --

13 DR. ROSAL: For a two phase flow you have
14 to have a larger tap than for a single phase flow.

15 CHAIRMAN WALLIS: Yes, otherwise you can
16 get a bubble in the hole, or a drop on the hole.

17 DR. ROSAL: And it stays there.

18 DR. HOCHREITER: As I said, one of the big
19 things that is different in this facility is the size
20 of these windows. These windows are almost a foot.
21 And we positioned the windows to be able to view
22 spacer grids.

23 We also heat the windows, just like we
24 heat the housing. In fact, are clam-on radiant
25 heaters, we use to heat the windows. And then we can

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1 photograph through here, we also use a digital camera,
2 laser illuminated digital camera system.

3 CHAIRMAN WALLIS: You try to keep the
4 windows dry, then?

5 DR. HOCHREITER: Yes, until the quench
6 front on the rods basically approaches, and then it
7 basically overwhelms.

8 CHAIRMAN WALLIS: So droplets that come up
9 there evaporate when they hit the window?

10 DR. HOCHREITER: Well, they probably don't
11 even hit the window because the window is so high.

12 DR. KRESS: Now, you take photographs of
13 the windows?

14 DR. HOCHREITER: Yes, I'm going to show
15 you some of the results of the data, and we will look
16 at a film clip.

17 These are traversing steam probes, okay?

18 DR. KRESS: To get the steam temperature?

19 DR. HOCHREITER: To get the vapor
20 temperature.

21 DR. MOODY: What window material do you
22 use?

23 DR. HOCHREITER: Quartz.

24 DR. MOODY: Quartz. You are not etching
25 your quartz yet?

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1 DR. HOCHREITER: No, it cracks first.

2 DR. MOODY: We had an awful lot of quartz
3 in our lab.

4 DR. SANJOY: We went to sapphire.

5 DR. HOCHREITER: We've had a lot of
6 problems with the windows, because just a small
7 distortion in the bundle, in the housing, and you have
8 to use a high temperature seal.

9 These seals were like 800 dollars each.
10 And then when you tighten down, because you have such
11 a large window, any distortion that you are trying to
12 compensate for, with the seal, you wind up cracking
13 the edge of the windows.

14 So, again, we lost time because we were
15 forever taking windows out, replacing windows,
16 replacing seals, and so forth. And it really became
17 a problem.

18 This is what these traversing steam probes
19 look like. We have three 15 mil thermacouples which
20 are, basically, held onto a piece of inconel shim
21 stock, and that is what is being routed around.

22 These can move in and out between the
23 subchannels. For the majority of the tests these
24 probes were positioned at the center of subchannels.
25 But I'm going to show you data for a probe being at

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1 the center of a subchannel, and for a probe being at
2 a gap between two rods.

3 These, because they are so small, and
4 again these tests are sort of quasi-steady state, you
5 will measure the vapor temperature, the non-
6 equilibrium vapor temperature for a much, much longer
7 time period, than we ever achieved in FLECHT, or
8 FLECHT SEASET, okay?

9 The quench front can almost be within a
10 foot or less before these things will totally
11 completely wet. Notice totally, completely wet. You
12 will get dips down to the saturation temperature.

13 And at least I have an interpretation of
14 what you should use for the steam temperature.

15 DR. RANSOM: And what is time constant for
16 those?

17 DR. HOCHREITER: 15 mil TCs, I don't know,
18 I don't remember. Short.

19 CHAIRMAN WALLIS: So you correct for
20 radiation, you calculate the radiation heat flux, and
21 you have a correction for the --

22 DR. HOCHREITER: Yes. Now, we haven't
23 done it in these thermacouples, these specific
24 thermacouples. We did those types of calculations on
25 other bare thermacouples we used, in previous

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1 experiments, and on the aspirating thermacouples we
2 are using FLECHT SEASET.

3 And the temperature levels for the rods
4 are actually relatively low here. So the radiation
5 effects, I think, are going to be small. Because they
6 were small, at much higher temperature levels, for
7 previous experiments.

8 DR. RANSOM: There must be an error in
9 your report. You say here it is .813 millimeters,
10 those are much smaller than that, I believe.

11 DR. SANJOY: He says .15 inches.

12 DR. RANSOM: Well, it is written here
13 .813.

14 DR. HOCHREITER: Well, we probably screwed
15 up.

16 DR. SANJOY: Because there are two or
17 three different thermacouples.

18 DR. HOCHREITER: Oh, that is correct, I'm
19 sorry. Vic, there are different thermacouples. There
20 is another set of thermacouples, and I don't have a
21 figure for those.

22 DR. RANSOM: It says the vapor or steam
23 temperature will be measured using miniature
24 thermacouples having a diameter of 1.813 millimeters.

25 DR. HOCHREITER: I think those refer to

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1 the thermacouples which we attached to the spacer
2 grid.

3 DR. RANSOM: Yes, it says they are
4 attached to the spacers, and to the traversing steam
5 probe rates all having a diameter of .381.

6 DR. HOCHREITER: We put additional vapor
7 temperature measurements attached to these spacers,
8 and had them point down, brought the instrumentation
9 out across the spacer, over to the pins that were in
10 the corner of the bundle, down those pins, and out the
11 bundle.

12 We also had temperatures which were,
13 thermacouples which were brazed into the metal of the
14 spacer. And those were routed across the spacer, back
15 over to the pins that were on the outside of the
16 bundle, and brought out of the bundle.

17 So we can measure the spacer temperature,
18 the vapor temperature. Of course we had rod
19 temperatures measurements. I don't have a figure to
20 show this, but what we did, when we set up the heater
21 rod instrumentation, and maybe I should go back to --

22 DR. RANSOM: The heater rods have
23 thermacouples on the inside of the --

24 DR. HOCHREITER: Yes, on the inside of the
25 cladding.

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1 We know there is going to be a heat
2 transfer enhancement downstream of the spacers,
3 because the Oakridge data show that. Actually we
4 didn't have any data of our own that showed that. But
5 primarily looking at the Oakridge data I can't think
6 if there is another set of data we looked at.

7 And I had developed a real simple
8 exponential decay multiplier that you apply to a
9 convective heat transfer coefficient, based on single
10 phase data.

11 We use that prediction to basically pick
12 the positions for the thermacouples downstream of the
13 spacer, okay? And we would look at these inner five
14 rods, and choose different rods, and symmetrical
15 positions, where we could basically measure the
16 detailed temperatures downstream of the spacers.

17 We also set up the traversing temperature,
18 vapor temperature measurements to measure the
19 temperature of the vapor, downstream of the spacers.
20 And we would have two or three of these between spacer
21 grids.

22 So we can get an idea of what the vapor
23 temperature behavior was. Then we had vapor
24 temperature probes sticking off the grid, pointing in
25 the upstream direction to measure the vapor

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1 temperature coming into the spacer grid.

2 So we had a lot of instrumentation,
3 detailed instrumentation, in and around the spacers,
4 because the feeling was that the spacer grids have a
5 first order effect on the disperse flow of film
6 boiling, because they are going to change the drop
7 sizes.

8 They are going to change the amount of
9 mixing that is in the flow. Now, you can't figure
10 that all out from one reflood test. So that is why in
11 the program we were going to run the steam cooling
12 test, only, and look at the convective heat transfer
13 behavior, particularly with these spacers, then do
14 droplet injection, and look at what happens to the
15 steam cooling behavior when you inject droplets with
16 these spacers.

17 DR. KRESS: Larry, when I was looking at
18 the Oakridge data that effect was in there, that you
19 said. And I couldn't decide, at first, whether this
20 was an enhanced turbulence, entrance reeds in effect,
21 or the effect of droplets getting broken up.

22 And I started using a Webber number
23 criteria to get the droplet size.

24 DR. HOCHREITER: Right.

25 DR. KRESS: And what I had trouble was,

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1 once I broke it up with the Webber number, they were
2 always that size. And I didn't get any enhancement
3 going through subsequent ones.

4 So I had to build into the model, an
5 agglomeration model of some sort, to make the droplets
6 get bigger again so I could re-break them up. And so
7 I had trouble. I finally concluded this was more a
8 breakup of the profile, velocity profile, into
9 entrance reason effect, is what I finally concluded.

10 But I don't know of --

11 DR. HOCHREITER: Well, that is exactly why
12 we want to do this experimentally, but separate these
13 effects out. So we will run steam cooling tests only,
14 and get that effect. Then we will introduce drops,
15 and we will look at what the change is in the steam
16 cooling.

17 Because I think there are other effects,
18 in addition to drop breakup. Steve alluded to this
19 earlier. The drops seem to do something irregardles
20 of the grids, to enhance convection.

21 CHAIRMAN WALLIS: Don't you get bigger
22 drops after the grid because you have a film on the
23 grid, which gets re-entrained again?

24 DR. HOCHREITER: That is not what our
25 measurements show.

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1 CHAIRMAN WALLIS: You don't get that?

2 DR. HOCHREITER: No, it showed just the
3 opposite.

4 CHAIRMAN WALLIS: You think the grid is
5 dry, then?

6 DR. HOCHREITER: No, most of the tests the
7 grids are wet, because we measure it.

8 CHAIRMAN WALLIS: Usually drops which come
9 off a film are bigger than the ones in the flow.

10 DR. HOCHREITER: I know. So 1.9 times
11 whatever.

12 DR. KRESS: The trouble with trying to
13 invoke some agglomeration of droplets to make them
14 bigger, is that there were too few of them in there,
15 if I used any ordinary agglomeration type of -- they
16 didn't see each other.

17 DR. HOCHREITER: It is a very sparse
18 population.

19 CHAIRMAN WALLIS: But, Tom, your model was
20 based on your imagination?

21 DR. KRESS: Yes, I was looking at the
22 Oakridge data and trying to imagine what was going on.
23 That is exactly right.

24 CHAIRMAN WALLIS: He is going to have
25 reality checks.

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1 MR. SCHROCK: Larry, I'd like to come back
2 with my earlier question about the grid spacer and
3 whether your grid spacer is going to provide
4 information that will be applicable to actual
5 reactors.

6 After I looked at it, then I have doubts.
7 I mean, you are convinced that the grid spacer has a
8 first order effect on the rod bundle heat transfer
9 downstream, because it dictates drop size
10 distribution.

11 DR. HOCHREITER: And turbulent mixing.

12 MR. SCHROCK: Okay, and whatever else.
13 But when I look through this thing, there is very
14 little of the cross section that is obstructed by
15 those mixing veins, very little.

16 DR. HOCHREITER: Do you know what is
17 misleading, the rods aren't in here.

18 MR. SCHROCK: I know, but the mixers don't
19 go all around.

20 DR. HOCHREITER: No, they don't.

21 MR. SCHROCK: So you've got portion of the
22 circumference has an area that is -- and droplets that
23 hit that are entrained, and then re-entrained.

24 DR. HOCHREITER: Or shattered.

25 MR. SCHROCK: And then the rest of it --

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1 were shattered? I don't know.

2 DR. HOCHREITER: Were shattered.

3 MR. SCHROCK: Well, they are hitting at an
4 angle, and I don't know what the velocity is, they are
5 pretty small drops to shatter, I think.

6 DR. HOCHREITER: Well, let me just -- you
7 may be correct, but that is what we have to find out.

8 MR. SCHROCK: Well, but what I'm concerned
9 with is will it then eventually be necessary for every
10 vendor to do detailed tests on his grid spacer to
11 establish correlations, or models, or something, that
12 are in the vendor's code, to deal with this part of
13 the reflood heat transfer?

14 DR. KRESS: I was under the impression you
15 could probably do it just with the area change.

16 DR. HOCHREITER: Well, that is the first
17 approach. But your point is very well taken, okay?
18 And the real question, I think, that NRR or Research
19 would be asking a vendor is show me why your grid, or
20 the performance of your grid is captured by what we
21 have tested. If you cannot show that, for whatever
22 reason you cannot show that, then you go run a test.

23 MR. SCHROCK: But in giving them a
24 requirement they might --

25 DR. HOCHREITER: Only for --

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1 MR. SCHROCK: -- feel on insecure grounds,
2 unless they had hard evidence that, yes, indeed the
3 geometry of the grid spacer is important, and has
4 first order of influence on the results.

5 DR. HOCHREITER: They know that that is
6 the case. The vendors know that that is the case.
7 That is why you do DNB testing.

8 The power capability of the fuel assembly,
9 these days, is tied up in the design of the spacers.

10 CHAIRMAN WALLIS: Does that mean that
11 every vendor has to duplicate your tests with their
12 own spacers?

13 DR. HOCHREITER: If they want more margin
14 than what we would show.

15 CHAIRMAN WALLIS: Or less. I mean, how
16 would we know whether they get more or less?

17 DR. HOCHREITER: Well, they have to -- I
18 would think that you would require them to make an
19 argument that whatever grid they put in is bounded by
20 whatever is tested.

21 CHAIRMAN WALLIS: Then it is much better
22 to have a test than an argument for something as
23 complicated as that grid.

24 DR. HOCHREITER: Sure, we can run more
25 tests.

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1 CHAIRMAN WALLIS: Maybe you set yourself
2 up to do a lot of tests now.

3 DR. HOCHREITER: Well, that was one of the
4 things that we talked about in the program, when we
5 first established the program. Because one of the
6 things that you could do is you could test to extremes.

7 This could represent one extreme, and
8 simple grids, like what you have in FLECHT, would
9 represent the other extreme. And if you can develop
10 a model that will predict both sets of those tests,
11 most of the grids are going to fall, should fall in
12 between, or be closer to this.

13 DR. SANJOY: What effect did FLECHT show?

14 DR. HOCHREITER: Very little, if any. And
15 I will show you a plot of that. Again, that is one of
16 the things, one of the new things that came out of
17 this program. Now, we weren't looking for it.

18 CHAIRMAN WALLIS: Now, I think it would be
19 good -- have you finished your description of this?
20 Then we will have a break, and then you can give us
21 results after the break. Would that be appropriate?

22 DR. HOCHREITER: That would be fine. One
23 of the other pieces of instrumentation we have is this
24 laser illuminated digital camera system, which we
25 photograph through a scattering sheet, through the

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1 windows, into the subchannel.

2 Now, the -- we've calibrated this thing,
3 actually, on a milling machine, so we know exactly
4 what the focal region is. But you are shooting
5 between the rods.

6 CHAIRMAN WALLIS: So you only have a very
7 short depth of focus in that? The rest of the
8 droplets are out of focus, is that what it is?

9 DR. HOCHREITER: The other droplets are
10 out of focus because you focus it into the center of
11 the bundle.

12 MR. SCHROCK: In the shadow, or out of
13 focus?

14 DR. HOCHREITER: Both, actually. Some of
15 them are shadow, some of them are out of focus. And
16 there is a software package that comes with this
17 system. And you describe in the software package the
18 boundary that you are looking at.

19 What we don't see, and what we exclude
20 from our sampling, are drops which are hidden by the
21 rods. So you would not count this drop, you would not
22 count this drop, you won't even see this drop. You
23 will count these drops.

24 CHAIRMAN WALLIS: But it takes a very
25 small mass fraction of drops, or let's say, void

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1 fraction, liquid fraction before you just have a fog,
2 and there is no direct line of sight between the laser
3 and the camera, at all.

4 DR. HOCHREITER: You don't have that many
5 drops.

6 CHAIRMAN WALLIS: You must have very, very
7 few drops, then?

8 DR. HOCHREITER: You do.

9 CHAIRMAN WALLIS: Then there is no way you
10 are going to measure your liquid fraction very
11 accurately with delta P cells.

12 DR. HOCHREITER: I said that. Yes, you
13 won't. Delta P cells are going to be most accurate at
14 the quench front.

15 CHAIRMAN WALLIS: Okay. So you are
16 interested in those few drops that make it way ahead
17 of all the others, and may do some cooling way
18 downstream?

19 DR. HOCHREITER: Well, you know, let me
20 show you the stuff first.

21 CHAIRMAN WALLIS: Okay.

22 DR. HOCHREITER: We can talk about the
23 matrix for a minute. We did run tests over this range
24 of conditions. This was not successful, this
25 overheated, and we had to terminate the test.

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1 But the pressure -- we primarily were
2 concentrating on flooding rates around one inch a
3 second, plus a whole series of tests at six inches a
4 second, a few tests at eight inches a second.

5 The six inches a second test were
6 basically to look at inverted annulus from boiling.
7 This is where the delta P cells would be the most
8 accurate, because you have the most mass in the
9 bundle.

10 And then look at dispersed flow film
11 boiling, where the flooding rates are one inch a
12 second. We looked over this pressure range, a wide
13 range of subcoolings.

14 Our temperatures, our initial
15 temperatures, most of the tests were run at 1,400
16 degrees fahrenheit, and the power, most of the tests
17 were run with .4 kilowatts per foot, and the power was
18 held constant.

19 And, again, this was to, basically,
20 stretch the transient out in time, and give you more
21 of a quasi state of --

22 MR. SCHROCK: That seems very low.
23 Earlier you were talking about eight kilowatts per
24 foot.

25 DR. HOCHREITER: That is the total power

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1 of the rod.

2 CHAIRMAN WALLIS: Why don't you use
3 international units?

4 DR. HOCHREITER: Because this is America.

5 DR. BAJOREK: Larry, I think you said
6 originally that the initial steady state power is
7 15/16 kilowatt per foot.

8 DR. HOCHREITER: For the plant, that was
9 for the plant.

10 DR. BAJOREK: For the plant. What this
11 is, this is at decay power.

12 DR. HOCHREITER: Okay, thank you. I've
13 already kind of said this already, that the grids have
14 a significant effect. Maybe before we get into the
15 data we could look at this film.

16 CHAIRMAN WALLIS: Well, you said this is
17 America, but most students, our students are all told
18 international units. They get very irritated when
19 they see things like inches and they don't know what
20 to do with them.

21 DR. HOCHREITER: Yes, I know, I'm teaching
22 an undergraduate course in reactor engineering, and I
23 make them use english units, they hate it.

24 CHAIRMAN WALLIS: These are in American
25 thermal units, are they?

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1 DR. HOCHREITER: Well, they are British.
2 This is a spacer grid.

3 CHAIRMAN WALLIS: This is a movie, now?

4 DR. HOCHREITER: This is a movie.

5 CHAIRMAN WALLIS: Maybe we need the lights
6 down.

7 DR. HOCHREITER: This is being heated up
8 adiabatically, so this is red, this is red, and this
9 is pretty poor.

10 CHAIRMAN WALLIS: It is going to get
11 redder, is it?

12 DR. HOCHREITER: It is pretty red right
13 now.

14 CHAIRMAN WALLIS: Why are they so wiggly,
15 those rods?

16 DR. HOCHREITER: Why are they so wiggly?
17 I think it is more because the camera is --

18 CHAIRMAN WALLIS: They don't look
19 straight, they've got bulges, and wiggles, and --

20 DR. HOCHREITER: I think the camera is at
21 an angle here.

22 CHAIRMAN WALLIS: Is it the heat flux, is
23 it some thermal boundary layer distortion?

24 DR. HOCHREITER: No, I think it is a
25 camera. What you are seeing is reflood has started.

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1 This is still hot below the grid, this is dark. So
2 there is good cooling downstream on the grids.

3 CHAIRMAN WALLIS: It is not obvious to me.

4 DR. RANSOM: Is that just steam going
5 through there?

6 DR. HOCHREITER: Steam, and it is hard to
7 see with this film, but drops are going through.

8 CHAIRMAN WALLIS: The rods look bigger
9 downstream than upstream. And they don't --

10 DR. HOCHREITER: That was really tricky to
11 me.

12 CHAIRMAN WALLIS: They don't look
13 continuous.

14 DR. HOCHREITER: Well, they are.

15 CHAIRMAN WALLIS: They have a jog in them.
16 Those are the rods, those things, those shiny things
17 are the rods downstream?

18 DR. HOCHREITER: Yes, these are the -- the
19 shiny hot things.

20 CHAIRMAN WALLIS: Why is it so dark in
21 between them?

22 DR. HOCHREITER: This is the spacer grid.

23 CHAIRMAN WALLIS: No, no, between the
24 shiny rods downstream.

25 DR. HOCHREITER: Why is it so dark in

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1 here? Because it is cooler. If you come up here you
2 can see drops zipping past her.

3 MR. SCHROCK: Yes, I can see that from
4 here, even. But what is the background there, what is
5 hot behind the lower portion?

6 DR. HOCHREITER: More rods.

7 MR. SCHROCK: Now, is there a metal back
8 behind there that is glowing red?

9 DR. HOCHREITER: I don't quite understand.

10 MR. SCHROCK: Well, the back wall of the
11 channel is what?

12 DR. HOCHREITER: Well, the back wall of
13 the channel is going to be seven rows away.

14 DR. RANSOM: So you are looking at an
15 angle.

16 MR. SCHROCK: In spite of that, you are
17 looking at a clear shot through there, and it --

18 DR. HOCHREITER: No, it is not a clear
19 shot, because you are looking at somewhat of an angle,
20 because otherwise you would see all the way through
21 these rods.

22 MR. SCHROCK: You are not seeing all the
23 way through.

24 CHAIRMAN WALLIS: So there is a whole host
25 of droplets in between those rods down below?

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1 DR. HOCHREITER: There are drops and steam
2 that are coming up through here.

3 CHAIRMAN WALLIS: Then they all go dark
4 downstream.

5 DR. HOCHREITER: So you can see much more
6 of the effect up here.

7 CHAIRMAN WALLIS: Why do they go dark
8 downstream?

9 DR. HOCHREITER: Because of the cooling.

10 DR. RANSOM: Does that look like the
11 entrainment on that spacer grid? I can see something
12 fluctuating off of it.

13 DR. HOCHREITER: Right here?

14 DR. RANSOM: Yes.

15 DR. HOCHREITER: Probably.

16 CHAIRMAN WALLIS: What does cooling have
17 to do with the color of the droplets?

18 DR. HOCHREITER: It is not the droplets,
19 it is the rods. Graham, these are rods.

20 CHAIRMAN WALLIS: Those shiny things are
21 rods?

22 DR. HOCHREITER: Yes.

23 CHAIRMAN WALLIS: But the dark spaces in
24 between are droplets.

25 DR. HOCHREITER: No, it could be more rods

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1 behind here, which are also dark and cooled.

2 CHAIRMAN WALLIS: Oh, I thought you were
3 looking right through the rods.

4 DR. HOCHREITER: No. This is at a slight
5 angle.

6 MR. SCHROCK: In the bottom picture you
7 can almost see the outline of the edge of the next row
8 of rods?

9 DR. HOCHREITER: Right. Bottom line is,
10 hot, cold.

11 CHAIRMAN WALLIS: I guess the
12 thermacouples show that?

13 DR. HOCHREITER: Yes.

14 CHAIRMAN WALLIS: Now, there seems to be
15 some pulsations going on.

16 DR. HOCHREITER: It is not perfectly
17 steady.

18 CHAIRMAN WALLIS: It looks like a lot of
19 pulsations now have developed.

20 DR. SANJOY: The quench front is
21 approaching?

22 DR. HOCHREITER: Quench front is about ten
23 feet away.

24 CHAIRMAN WALLIS: The quench front is down
25 below somewhere?

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1 DR. HOCHREITER: Yes.

2 CHAIRMAN WALLIS: Are we going to see it?

3 DR. HOCHREITER: I don't think.

4 DR. SANJOY: You can see it, but it takes
5 a long time.

6 DR. HOCHREITER: If we want to go off for
7 coffee and come back.

8 CHAIRMAN WALLIS: Now, do those rods go
9 red again before the next spacer grid?

10 DR. HOCHREITER: I actually don't really
11 know because the temperature goes back, so I think it
12 does.

13 DR. KRESS: They do in the Oakridge test,
14 they get hot again at the top.

15 CHAIRMAN WALLIS: Now, what are those
16 shiny white bubbly things that are above the grid?

17 DR. HOCHREITER: These are probably the
18 veins, and you are probably seeing the liquid.

19 CHAIRMAN WALLIS: Those are veins.

20 DR. HOCHREITER: I would say the velocity
21 in the bundle is some place between and 60 feet a
22 second.

23 DR. MOODY: You are injecting a spray?

24 DR. HOCHREITER: No, this is a reflood of
25 inch a second.

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1 DR. MOODY: Because of the quench, all
2 right, that is sending the droplets up in the vapor,
3 then.

4 DR. HOCHREITER: Yes, it is easier to see
5 them here than it is here.

6 MR. SCHROCK: How far is the quench front
7 below this?

8 DR. HOCHREITER: I can't answer that, I
9 would have to go back and --

10 MR. SCHROCK: Is it a long way, or short?

11 DR. HOCHREITER: I think so, yes.

12 MR. SCHROCK: Long ways.

13 DR. HOCHREITER: Although you are starting
14 to see this cool down now.

15 CHAIRMAN WALLIS: Why didn't that get
16 cooled before? Because when the quench front was
17 below that, it was above a spacer.

18 DR. HOCHREITER: I'm sorry?

19 CHAIRMAN WALLIS: I mean, it just seems
20 funny that you have so much cooled so well up above.

21 DR. HOCHREITER: That is because the
22 spacer grid is mixing up this --

23 CHAIRMAN WALLIS: Why isn't --

24 DR. HOCHREITER: -- shattering drops --

25 CHAIRMAN WALLIS: -- the red part cooled

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1 by the spacer which is below it?

2 DR. HOCHREITER: Because there is another
3 two feet before the next spacer.

4 CHAIRMAN WALLIS: Oh, it is a long way.

5 DR. HOCHREITER: There is like 40 to 45 --

6 DR. SANJOY: Where is the --

7 DR. HOCHREITER: -- spacers.

8 DR. SANJOY: -- flux peak?

9 DR. HOCHREITER: Ralph, do you remember
10 which elevation this was?

11 DR. ROSAL: It is 105, that grid is 110.

12 DR. HOCHREITER: So the flux peaks right
13 about here.

14 DR. ROSAL: Elevation for the power, it is
15 below the grid.

16 DR. HOCHREITER: Now everything is
17 starting to get cool. So the quench front is moving
18 up.

19 MR. SCHROCK: Now, why do they look
20 different in the two zones?

21 DR. HOCHREITER: Why do they look
22 different?

23 MR. SCHROCK: Why are the rods shiny on
24 top and not --

25 DR. ROSAL: Because of the light that is

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1 shining on the window.

2 CHAIRMAN WALLIS: Okay, so you can change
3 what you see by how you illuminate it.

4 MR. SCHROCK: Are they glowing red, is
5 that --

6 DR. HOCHREITER: At the beginning of the
7 test they were glowing red.

8 MR. SCHROCK: When the test is first
9 initiated, and that top zone is all glowing red, then
10 if you can view the whole length of it, do you see the
11 precursory cooling affecting the lower part of it
12 first, and then propagating up into the upper part of
13 it?

14 DR. HOCHREITER: It is really not
15 affecting this very much at all.

16 MR. SCHROCK: No, I'm talking about this
17 upper zone now. What you showed us, you began with it
18 already cool there. But if I could see the top of
19 that?

20 DR. HOCHREITER: It would probably be red.

21 MR. SCHROCK: Still glowing red?

22 DR. HOCHREITER: Yes.

23 MR. SCHROCK: So your model is going to
24 have to take that kind of thing into account.

25 CHAIRMAN WALLIS: That thing which is up,

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1 there is a light just above your head there?

2 DR. HOCHREITER: You are starting to --
3 this is starting to get liquid on the --

4 CHAIRMAN WALLIS: The thing above your
5 head, there, is a light, that is why it is white
6 above?

7 DR. HOCHREITER: You mean right in here?
8 See, you are starting to get liquid up, now. A lot of
9 liquid.

10 CHAIRMAN WALLIS: Something is bouncing up
11 and down.

12 DR. HOCHREITER: We may have already
13 quenched this down here. It is hard to see where the
14 quench front is.

15 DR. MOODY: That is real time?

16 DR. HOCHREITER: Actually I think that
17 this is faster than real time.

18 DR. SANJOY: That is oscillatory behavior.

19 CHAIRMAN WALLIS: Yes, it does look
20 oscillatory.

21 DR. HOCHREITER: This is typical behavior
22 for a reflood test.

23 CHAIRMAN WALLIS: It doesn't look very
24 analyzable to me.

25 DR. HOCHREITER: Well, it is time average,

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1 your calculation is going to be averaging this over
2 time. It might be six months, a year.

3 But the -- if you induce system
4 oscillations they are much more pronounced. I mean,
5 they are huge oscillations that go up through the
6 entire bundle.

7 CHAIRMAN WALLIS: There are, even in your
8 tests?

9 DR. HOCHREITER: When we had poor pressure
10 control, yes.

11 CHAIRMAN WALLIS: But not in the Penn
12 State tests?

13 DR. HOCHREITER: No, in the Penn State
14 tests when we had poor pressure control you could get
15 large surges in the oscillations, and you would see it
16 on the data. You would see it in the thermacouples --

17 CHAIRMAN WALLIS: Which happens in the
18 reactor, do you get these large surges, or not?

19 DR. HOCHREITER: Again, according to Long
20 Sung Tong, reactors don't oscillate.

21 MR. SCHROCK: Larry why is it heating up
22 above the spacer grid? The spacer grid at that point
23 in the transient doesn't seem to be effective in
24 inducing any cooling.

25 DR. HOCHREITER: Right now, you mean?

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1 MR. SCHROCK: Yes, it is hotter up there
2 than it is down below.

3 DR. HOCHREITER: I think you are seeing
4 the shine.

5 DR. BAJOREK: Larry, right above, if you
6 raise your left hand, higher, higher, over to that,
7 right there, that is the light, that is the trouble
8 light.

9 MR. SCHROCK: Well, do they keep moving
10 the light around?

11 DR. BAJOREK: No, it was the same place.

12 MR. SCHROCK: It was bright down below
13 when you started out.

14 DR. BAJOREK: That was the rods. It
15 looked like the electric burners on a stove.

16 DR. HOCHREITER: Why don't we stop and
17 back this, rewind this thing? There is a combination
18 of things going on, light and --

19 CHAIRMAN WALLIS: We will take a break
20 after this movie, if that is okay with you.

21 MR. SCHROCK: They really did look like
22 they were distorted when they were red hot. What do
23 you do to prevent axial compression when they heat?

24 DR. HOCHREITER: Axial compression?

25 DR. KRESS: They are only tied at one end,

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1 I think.

2 DR. HOCHREITER: They are supported at the
3 top, and they go through the bottom. The rods are
4 supported at the top, they screw into a top plate.
5 And there are o-ring seals at the bottom, so the rods
6 grow downward in a thermal expansion.

7 MR. SCHROCK: But they connect to some
8 rigid piping somewhere, so --

9 DR. HOCHREITER: They go into a molten
10 pool, which provides, basically, the ground to return
11 current pool.

12 MR. SCHROCK: SO they just hang there?

13 DR. HOCHREITER: Yes.

14 DR. SANJOY: What is the molten metal?

15 DR. HOCHREITER: Lead.

16 CHAIRMAN WALLIS: This is how you get the
17 electrical contact?

18 DR. HOCHREITER: Take it almost right back
19 to the beginning.

20 CHAIRMAN WALLIS: We can watch it
21 backwards.

22 DR. MOODY: Larry, that far left strip, is
23 that the other side of the --

24 (Everyone speaks at the same time.)

25 DR. MOODY: It looks like a window on the

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1 very left strip, there.

2 DR. HOCHREITER: Here?

3 DR. MOODY: No, now move over -- yes, up
4 and down there.

5 DR. HOCHREITER: I think this would just
6 be the aluminum insulation, the aluminum coating
7 around the --

8 DR. MOODY: When we saw that activity in
9 the other, water and so forth, you could see something
10 in that section too. I just wondered --

11 DR. HOCHREITER: Here?

12 DR. MOODY: Yes.

13 DR. HOCHREITER: I hope not. That means
14 the window was leaking.

15 DR. MOODY: Well, it looked like looking
16 through a window. Is it angled such that we are seeing
17 some of the same activity in that strip?

18 DR. HOCHREITER: Well, I hope not. Well,
19 if the window leaks, this is hot --

20 CHAIRMAN WALLIS: So you want to run it
21 again, or something? What do you want to do, Larry?

22 DR. HOCHREITER: That is your choice.

23 CHAIRMAN WALLIS: Are we going to see
24 anything different the second time?

25 DR. HOCHREITER: I think you will, yes.

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1 CHAIRMAN WALLIS: Well, what I suggest we
2 do is we take a break, and you run the movie during
3 the break, and if anybody wants to see it again, they
4 can see it. Then we can have an informal discussion,
5 off the record, during the break if that helps.

6 We will break for 15 minutes, come back at
7 3:25, and we will run the movie during the break for
8 those who want to see it again. But we will break
9 now.

10 (Whereupon, the above-entitled matter
11 went off the record at 3:11 p.m. and
12 went back on the record at 3:25 p.m.)

13 CHAIRMAN WALLIS: Let's come back into
14 session.

15 We are now going to hear what we've been
16 looking forward to, which is the description of some
17 of the data produced by this wonderful setup.

18 DR. HOCHREITER: Okay. What I have is
19 data for two tests, and I was going to run through
20 that. And maybe after you see the first test we can
21 go through the second test faster.

22 The main change is, primarily, the
23 pressure. So this is a 20 PSI experiment, one inch a
24 second flooding rate, 1,4000 degree initial
25 temperature, 20 degrees subcooling.

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1 The first thing I would point out is the
2 duration of the test. It is really very long. And
3 the reason for this is using constant power. And you
4 tend to, basically, be able to get longer periods of
5 time of dispersed flow of film boiling.

6 And this is the quench front from the
7 heater rods as the quench basically moves up. So this
8 is basically quench elevation versus time.

9 DR. KRESS: That doesn't look like one
10 inch per second.

11 DR. HOCHREITER: Why doesn't it look like
12 one inch a second?

13 DR. KRESS: Well, between 400 and 600
14 seconds, that is 200 seconds, and it would be 200
15 inches change, and I don't see 200.

16 CHAIRMAN WALLIS: I think is --

17 DR. HOCHREITER: No, one inch a second is
18 the cold flooding rate.

19 CHAIRMAN WALLIS: It is the flow rate of
20 water.

21 DR. HOCHREITER: Cold flooding rate.

22 DR. KRESS: I see what you mean. You are
23 losing -- that stuff with steam.

24 DR. HOCHREITER: About 95 percent of it.

25 DR. KRESS: Yes, I see.

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1 CHAIRMAN WALLIS: How do you define quench
2 front?

3 DR. HOCHREITER: Let me show you in a
4 figure for a minute. Can I hold that for a second?

5 The next slide is a calculation for one
6 parameter, and then the other is data. This is where
7 we calculate the saturation line to be, the bundle,
8 this is where the energy comes.

9 And, again, the power is constant, the
10 flow is constant, subcooling is constant in the test.
11 So basically you would start to boil at this point.
12 And the red line is basically the rod quench front,
13 the black line is the housing quench front. These are
14 data.

15 So this region between the red line and
16 the blue line, basically is a two phase region, where
17 you basically have nuclear boiling. And so you have
18 production of steam in this region, in addition to the
19 steam that is generated when you quench the rods from
20 the stored energy release of the rods themselves.

21 CHAIRMAN WALLIS: You have steam created
22 above the quench front too.

23 DR. HOCHREITER: You have steam created
24 above the quench front due to evaporation of the
25 droplets.

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1 This is something that is very different
2 than other reflood experiments, for two reasons. One,
3 most of the tests were run with higher subcoolings,
4 typically 150 degrees subcooling.

5 Two, the power was not constant. So if
6 you would plot the saturation line for those
7 experiments it basically followed the quench front,
8 and then peeled it away from the quench front at about
9 this time period here.

10 So, again, by running with a constant
11 power you basically have expanded the region boiling
12 below the quench front, but then you've expanded the
13 time duration of the test.

14 DR. KRESS: So if I look below that blue
15 line?

16 DR. HOCHREITER: It is single phase
17 liquid.

18 DR. KRESS: -- would be one inch per
19 second, then?

20 DR. HOCHREITER: Below this, yes.

21 DR. KRESS: It doesn't look like it.

22 DR. HOCHREITER: Well, probably because I
23 have only drawn it to here.

24 DR. KRESS: Okay.

25 DR. RANSOM: What do you mean by sat line?

1 That position is where you exceed the saturation
2 temperature, is that right?

3 DR. HOCHREITER: Of the coolant, yes.
4 Just from an energy balance.

5 DR. SANJOY: It is a very low reflood
6 rate?

7 DR. HOCHREITER: Right, low reflood rate,
8 low subcooling.

9 Now, what I've got are a bunch of plots of
10 temperatures above and below spacer grids at different
11 elevations. This is for the grid that is at the 69
12 inch elevation, the black thermocouple is thermocouple
13 on the rod, and the inner five by five is located at
14 this elevation.

15 The green one, which I've colored in, is
16 a thermocouple here. You asked about where the quench
17 front is. Quench front is defined, usually, by the
18 need in this curve. Because that is where we think
19 that you start to get wetting.

20 CHAIRMAN WALLIS: Where it begins to turn
21 down rapidly?

22 DR. HOCHREITER: Very rapid, yes. And
23 we've used a criteria to look at this, so many degrees
24 per second for quenching.

25 Now the thing that is very apparent from

1 this figure is that the cooling, as we saw on the
2 film, downstream, is better than the cooling upstream.
3 And that is really reflected in this temperature
4 difference.

5 CHAIRMAN WALLIS: Until the quench front
6 gets close?

7 DR. HOCHREITER: Right. And then there is
8 a difference here, because there is an elevation
9 difference between the two T cells.

10 I've got a series of these plots, and I
11 also have vapor temperature measurements. These are
12 vapor temperature measurements, again, upstream and
13 downstream of the quench front.

14 This steam probe is up here, it is black
15 -- I'm sorry. Can you hear me?

16 So we have a steam probe here, and a steam
17 probe here. This one is at 83 inches above the grid,
18 this one is below the grid at 16 inches. You don't
19 see a lot of difference in through here, but you see,
20 again, a continuation of the vapor superheat, really
21 out for a pretty long period of time.

22 Now, these --

23 DR. SANJOY: These are the same run that
24 you --

25 DR. HOCHREITER: Same run. The way, at

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1 least, I'm interpreting the steam probe measurements,
2 and this is open for debate, I probably shouldn't have
3 said that, is that the real steam temperature is the
4 peaks of this.

5 This is really the thermocouple seat water
6 droplets. What is unique about these measurements is
7 that you see a persistence of superheated vapor for a
8 long time.

9 In the previous reflood experiments that
10 I have looked at, in tests which I have run myself,
11 you would not get vapor superheats that would be
12 persistent for as long a period of time, and at an
13 elevated superheated temperature.

14 CHAIRMAN WALLIS: What is interesting to
15 predict is not just the peak, but what seems to be the
16 lower, which is around 200 degrees C, in your green
17 curve, there is a whole range of --

18 DR. HOCHREITER: Well, or the difference.

19 CHAIRMAN WALLIS: Why is it bottoming out
20 at 200?

21 DR. HOCHREITER: In here?

22 CHAIRMAN WALLIS: Yes.

23 DR. HOCHREITER: I don't know, I don't
24 have a good answer for that. This is a saturation
25 temperature, essentially, here. The 20 PSI test,

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1 saturation is 228 degrees fahrenheit.

2 CHAIRMAN WALLIS: Well, maybe that is the
3 radiation from the rods.

4 DR. HOCHREITER: That is keeping it up
5 here?

6 CHAIRMAN WALLIS: Right. Because quench
7 front comes by around 500 or something?

8 DR. HOCHREITER: Well, that is what I was
9 going to show next. This is at 73 inches.

10 CHAIRMAN WALLIS: Well, it is not the same
11 scale of time.

12 DR. HOCHREITER: Well, I know, so that is
13 here. It is about 700 seconds, this thing is
14 quenching, going to saturation at about 600 seconds.

15 CHAIRMAN WALLIS: But the previous slide
16 is much better, yes. So the thermocouple quenches
17 before the rods do, before the clad does?

18 DR. HOCHREITER: The steam probes tend to
19 quench before the rods do, yes. This is quenching at
20 about 600 seconds. Actually, this is pretty close.

21 CHAIRMAN WALLIS: Your scales aren't the
22 same, are they?

23 DR. HOCHREITER: No, but this time and
24 this time are the same. But, again, I have never run
25 experiment, or seen tests where the vapor remains

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1 superheated for a longer period of time, as the rods
2 start to quench.

3 CHAIRMAN WALLIS: So that is something
4 that your theory is going to explain, or model?

5 DR. HOCHREITER: Well, somebody's model,
6 yes.

7 CHAIRMAN WALLIS: Not yours?

8 DR. HOCHREITER: I don't know, maybe. So,
9 I mean, to me this is great stuff for any kind of an
10 advance code, because you have to try to predict this.
11 Now, again, I think you have to use some constructive
12 interpretation of the measurement.

13 And it is really the peaks that I think
14 you want to look at. And then it really gets fuzzy in
15 here.

16 DR. SANJOY: What is a bit surprising is
17 that the green and the black back there --

18 DR. HOCHREITER: Are about the same?

19 DR. SANJOY: Yes.

20 DR. HOCHREITER: I know. You don't see
21 that in all of them. Let me run through some more.
22 This is low, this is fairly low in the bundle.

23 CHAIRMAN WALLIS: Maybe it is only steam
24 up there, there is no water at all.

25 DR. HOCHREITER: No, there is water. If

1 there is only steam you would not see this.

2 CHAIRMAN WALLIS: You wouldn't?

3 DR. HOCHREITER: No.

4 MR. SCHROCK: What is the meaning of SP
5 and CT, that is on your location up there?

6 DR. HOCHREITER: CT is clad thermocouple,
7 ST is steam probe. So these are clad thermacouples
8 inside the heater rods, these are steam probes.

9 MR. SCHROCK: They are all temperatures?

10 DR. HOCHREITER: Yes, yes. I'm going to
11 get this all in the border. Now, this is another
12 elevation that is further up.

13 CHAIRMAN WALLIS: This is now in
14 centimeters a second?

15 DR. HOCHREITER: I have a foreign student
16 doing this. And by contract we have to give the NRC
17 this stuff in metric. The only problem is I don't
18 understand it. I do understand that.

19 CHAIRMAN WALLIS: Well, centimeter is not
20 a standard unit.

21 DR. HOCHREITER: So this is at, with the
22 grid at the 89 inch elevation. Again, this is a clad
23 temperature at 91 inches, and a clad temperature at 88
24 inches.

25 And you can see the effect of the spacer

1 grid is to drop this by over 200 degrees C.

2 CHAIRMAN WALLIS: Now, all these curves
3 are digitized, and recorded in electronic forms?

4 DR. HOCHREITER: Yes.

5 MR. SCHROCK: Where is the grain? Is that
6 the upper thermocouple on the plan?

7 DR. HOCHREITER: Yes. 91 inches.

8 DR. KRESS: Now, have you replotted these
9 anywhere as the temperature versus elevation?

10 DR. HOCHREITER: Yes.

11 DR. KRESS: Above the --

12 DR. HOCHREITER: Yes.

13 DR. SANJOY: But the first peak is about
14 the same, right?

15 DR. HOCHREITER: Yes, and this is probably
16 because this is right at the beginning of the test,
17 and there probably is no water.

18 CHAIRMAN WALLIS: So how does the steam
19 get heated so much as it goes through the grid?

20 DR. HOCHREITER: The steam is getting
21 cooled.

22 CHAIRMAN WALLIS: No, the next curve. The
23 steam probe is the next one. In this one the steam is
24 getting heated as it goes through the grid, isn't it?
25 Am I looking at something else?

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